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Sustainable Planning to Reduce Urban Flooding – an Interdisciplinary Approach

Bærekraftig planlegging for å redusere urbane flommer – en tverrfaglig tilnærming

Geir Torgersen

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Abstract

Statistics show that there is a global trend of increased frequency of urban flooding. Floods can be caused by rising rivers (fluvial) and heavy rain (pluvial). The work presented here has been restricted to the most frequent type in urban areas, floods induced by heavy rain. Most climate researchers seem to agree that the increased frequency of extreme weather is connected to global warming and climate change (CC). As more people want to live in urban areas, more land must be transformed from its natural site. This leads to more roofs and other sealed surfaces, which reduces the possibility to accumulate and infiltrate water. Conventional piped drainage systems, often designed decades ago for a specific maximum flow rates, will probably be unable to meet the increased volume of water. Sustainable planning of drainage systems covers a range of management practices, mostly associated with non-piped systems for drainage of surface water, as such systems more closely resemble the runoff pattern from a natural site. This concept, called Sustainable Urban Drainage System (SUDS), is considered a necessary step to accommodate the expected increase in urban runoff. Climate change, population growth and aging pipe systems are all important drivers for developing sustainable stormwater management systems to reduce the impact of urban floods.

Traditionally, the planning and development of drainage and sewer systems has been the responsibility of municipal engineers. The engineering approach, based on fixed design rules and on certain predictions, is often associated with piped systems. The sector is considered to be conservative, and the engineering culture is often referred to as a key barrier to the implementation of sustainable approaches in practice. To what extent extreme rainfall will affect the urban environment in the future, is highly uncertain. Thus, this study suggest that the urban flood challenge should be met with a flexible, interdisciplinary and holistic approach.

For several reasons, the papers included in this work apply statistical tools to complement conventional methods. First of all, the main objective has been to implement knowledge from non-engineering disciplines and develop innovative tools. Secondly, it was intended to raise awareness of the urban flood challenge, using statistical data based on affected houses and people in order to capture public interest. Finally, by analysing a wide range of relevant data, illustrate the diversity of 'points of attack' aiming to reduce the extent of urban floods.

The results of this work are presented in four scientific papers. In **Paper I** the results from a survey and national statistics on how SUDS and the urban flood issue were implemented by municipal engineers in Scandinavian countries are described. This study formed the basis for the subsequent work as it put priorities and measures up against other reasons to improve the drainage and sewer systems. The results indicated that Norway ranked flood prevention lower than Sweden and Denmark. It is suggested that to encourage the use of SUDS, the cities should be required to measure drainage efficiency, either by monitoring or by modelling the impact of preventive measures. The lack of such requirements from the Norwegian authorities seems to be one explanation to why engineers in Norwegian cities are less focused on flood prevention compared to engineers in Swedish and Danish cities.

In Papers II, III and IV, tools new to this area of research were introduced. They had in common that they all included statistical analyses based on experiences from actual urban flood events.

The study presented in **Paper II** was based on data from stormwater-related insurance claims and rainfall in Fredrikstad, Norway in the years 2006–2012. The main objective was to find characteristics of extreme rainfall and its influence on the extent of urban floods. To make the dataset more interpretable, Principal Component Analysis (PCA) was applied. Looking at different temporal scales, the results can be summarized in three key findings: First, the extents of claims peaked in the late summer period. This can be related to convective rain often occurring at that time of the year. Second, the amount of precipitation in the week or days ahead of an extreme rainfall influence the payouts from the insurance companies, and thus the soil wetness is of importance also in urban areas. Third, relatively less intensive, but more stable and long-lasting rain (duration >120 min) seemed to induce more claims than rainfall of shorter duration. The study indicates a correlation between extreme rainfall events and the extent of damages. The identification of these characteristics suggests that well-timed and flexible measures can be beneficial in terms of reduced flood risk for the society.

The main purpose of the study presented in **Paper III** was to investigate variables characterizing the surroundings of houses, which seem to have an impact on the exposure to urban floods. Addresses in Fredrikstad, Norway were selected for this analysis. They were either associated with a registered insurance claim caused by flooding or randomly selected as a reference sample. From these addresses, relevant variables were derived. A multivariate statistical model, Partial Least Squares (PLS) Regression, was applied to examine any pattern in the sample. The analysis confirmed that houses located near combined sewer mains and in concave curvature were susceptible to floods. Further, houses located in steep slopes seem to be less exposed. By using this method, it is possible to quantify and rank significant variables, which have an impact on urban flood damages within a region. Results from the PLS-models might provide input to professionals in the identification of flood-prone houses. It can also make residents aware of the risks and motivate them to implement preventive measures.

Reducing proprietors' fear of urban flood damages during heavy rain is a benefit component often overlooked in Cost-Benefit Analysis (CBA). Hence, the study presented in **Paper IV** can be included as a part of a socio-economic analysis intended to measure the welfare loss caused by insecurity to floods in monetary terms. A survey designed for a Contingent Valuation (CV) study was conducted. The statistical analysis indicated that the Willingness to Pay (WTP) increased as the respondents felt more exposed or being settled close to former flooded sites. The study showed that for people who did not feel exposed or had been affected, mean WTP per Household per year was quite stable around NOK 400[1]. This was contrary to people who were concerned, who on average were willing to pay 2-3 times more for security. Adding the benefits of reduced insecurity in CBAs, could justify higher investment in urban flood prevention. Furthermore, studies like this can raise awareness of a hidden psychological challenge for some people, which most people do not care much about.

The overriding issue in Papers II, III and IV was to apply innovative tools to complement traditional engineered solutions related to urban flood management. The overall idea was that techniques from non-engineering disciplines could enforce interdisciplinary collaboration and raise awareness of the urban flood challenge. Hopefully, the outcome of this work can contribute to innovative processes that have the power to accelerate the transition towards increased use of more flexible and sustainable methods aiming to reduce the urban flood risk.

[1] NOK 1 = €0.11 (2015)

Sammendrag

Over hele verden er det en økning i omfanget av urbane flommer. Flommer kan forårsakes både av elver som går over sine bredder (fluviale flommer) og av store lokale nedbørsmengder (pluviale flommer). Arbeidet som presenteres her er avgrenset til den vanligste kategorien av urbane flommer, de som er forårsaket av store regnmengder. De fleste klimaforskere er enige om at mer ekstremvær skyldes global oppvarming og klimaendringer. Siden flere mennesker vil bo i byer, må stadig mer areal endres fra sin naturlige tilstand. Dette medfører mer takflater og andre tette arealer som reduserer muligheten for å samle opp og infiltrere overflatevannet lokalt. Tradisjonelle rørbaserte løsninger har lang teknisk levetid og er ofte dimensjonert for flere år tilbake med de forutsetninger som gjaldt på det tidspunktet. Bærekraftig planlegging av overvannssystemer er en tilnærming som har til hensikt å sørge for en mest mulig naturlig drenering av overflatevannet. Dette kalles i internasjonal sammenheng ofte for Sustainable Urban Drainage System (SUDS). I Norge er dette assosiert med lokale løsninger, såkalt lokal overvannshåndtering (LOD). SUDS er vurdert som helt nødvendig for å ta hånd om den forventede økningen i avrenning fra urbane områder. Klimaendringer, befolkningsøkning og et stadig eldre ledningssystem er alle drivere for å utvikle mer bærekraftige overvannsløsninger og redusere omfanget av urbane flommer.

Tradisjonelt har ingeniører i kommunal sektor vært ansvarlige for planlegging og utvikling av forebyggende tiltak mot urbane flommer. Ingeniør-perspektivet er ofte basert på fastsatte dimensjoneringskriterier og bestemte prognoser og knyttes normalt til rørbaserte løsninger. Sektoren er regnet for å være konservativ, og ingeniørkulturen blir ofte regnet som en barriere når man skal tilrettelegge for bærekraftig tilnærming i praksis. Det er høyst usikkert hvordan omfanget av urbane flommer vil bli i framtiden. Utgangspunktet for denne studien er at denne utfordringen bør møtes med en fleksibel, tverrfaglig og helhetlig tilnærming.

Det er flere grunner til at artiklene som inngår i dette arbeidet bruker statistiske verktøy for å komplementere tradisjonelle metoder. For det første så har en av hensiktene vært å anvende kunnskap og verktøy utenfor den tradisjonelle ingeniørsfæren. Det har også vært et mål å bidra til mer allmenn oppmerksomhet rundt utfordringene med urban flom. Av den grunn er det antatt at statistiske data knyttet til flomrammede boliger kan skape økt offentlig interesse for dette temaet. En statistisk analyse av et bredt spekter av relevante data understreker også de forskjellige perspektivene som man kan innta for å redusere omfanget av urbane flommer.

Resultatene av dette arbeidet er samlet i fire vitenskapelige artikler. I **Artikkel 1** presenteres resultater fra en spørreundersøkelse samt nasjonal statistikk som viste i hvilken grad SUDS og urbane flommer var prioritert blant ingeniører i kommuner i de skandinaviske landene. Denne studien dannet grunnlaget for de senere artiklene fordi den satt prioriteringer og valg av tiltakstype opp mot andre grunner til å forbedre avløpssystemene. Resultatene indikerte at Norge rangerer forebyggende flomtiltak lavere enn Sverige og Danmark. Det er videre antydet at for å oppmuntre til å mer bruk av SUDS, så bør det være påkrevd å måle effekten av utførte tiltak, enten ved måling eller modellering. Mangel på slike krav fra norske myndigheter ser ut til å være en forklaring på hvorfor norske byer har mindre fokus på flom sammenlignet med svenske og danske byer.

I artikkel II, III og IV ble det benyttet verktøy som er relativt nye innen dette fagområdet. Alle disse verktøyene inkluderte statistiske analyser basert på reelle erfaringer fra urbane flommer.

Arbeidet presentert i **Artikkel II** tok utgangspunkt i overvannsrelaterte forsikringskrav og nedbørsdata registrert i Fredrikstad mellom 2006 og 2012. *Principle Component Analysis* (PCA) ble anvendt slik at datasettet skulle bli enklere å tolke. Hovedhensikten var å se etter karakteristiske trekk ved ekstremregn og hvordan det påvirker omfanget av urbane flommer. Ved å se på regnmengder over ulike tidsrom, kan resultatene oppsummeres i tre punkter: For det første så øker antallet forsikringskrav på sensommeren, noe som kan ha sammenheng med konvektiv nedbør som ofte opptrer på denne tiden av året. Videre kan det se ut som om nedbørsmengden i uken og dagen før et ekstremt regnvær har betydelig innvirkning på skadeomfanget. Det kan derfor synes som om endret avrenningskoeffisient på grunn av at bakken blir mettet av vann, kan være av betydning også i urbane områder. Det ser også ut til at relativt stabilt og langvarig regn (varighet > 120min) forårsaker mer skade enn intense regnvær av kortere varighet. Studien indikerte at det er et mønster mellom ekstremregn og omfanget av skader. Denne kunnskapen understreker betydningen av at riktig timing og fleksible tiltak, kan ha en nytteverdi for å redusere flomrisikoen for samfunnet.

Hovedhensikten med arbeidet presentert i **Artikkel III** var å undersøke variabler som var karakteristiske for området rundt et hus og som ser ut til å ha en betydning for eksponering mot urban flom. Fredrikstad i Norge ble valgt som studieområde i denne analysen. Addresser herfra ble valgt fordi de tidligere hadde hatt en registrert flomhendelse eller de ble tilfeldig valgt ut for å inngå i et referansegrunnlag. Fra alle disse adressene ble det utarbeidet et sett med relevante variabler. En multivariat statistisk modell, kalt *Partial Least Squares* (PLS) *Regression* ble benyttet for å undersøke eventuelle mønstre i datasettet. Modellen bekreftet at flom oftere blir registrert på boliger nær fellesavløpsledninger og i konkav kurvatur. Videre kan det synes som om hus i bratte skråninger er mindre eksponert. Ved å bruke denne metoden er det mulig å kvantifisere og rangere de variablene som ser ut til å ha en betydning for urbane flommer innenfor et område. Resultater fra PLS-regresjonene kan bidra til å identifisere boliger som er utsatt for flom. Det kan videre føre til at beboere blir klar over denne faren, noe som videre kan motivere dem til å gjøre forebyggende tiltak.

En komponent som ofte ikke blir tatt hensyn til i en nytte-kostnadsanalyse (CBA), er husholdningers utrygghet. Studien presentert i **Artikkel IV** kan inkluderes i en samfunnsøkonomisk analyse for å måle velferdstapet i kroner og øre, forårsaket av utrygghet for flom. Det ble utarbeidet en Betinget Verdsettingsstudie (CV) for å undersøke dette. Den statistiske analysen viste at betalingsvilligheten (WTP) økte for respondenter som følte seg mer eksponert og bor nær flomrammede områder. Studien viste videre at de som verken følte seg eksponert eller er rammet tidligere, har en gjennomsnittlig betalingsvillighet på 400 kr pr husholdning pr. år. De som derimot følte seg berørt var i gjennomsnitt villig til å betale 2-3 ganger mer for trygghet. Hvis man inkluderer redusert utrygghet i en CBA-studie, kan det forsvare høyere investeringer i flomforebyggende tiltak. Videre kan studier som dette skape oppmerksomhet om en utfordring som kan være en psykisk belastning for noen, men som for de fleste andre er et ukjent problem.

Fellesnevneren for artikkel II, III og IV var å bruke innovative verktøy for å komplementere tradisjonelle og ingeniørbaserte løsninger knyttet til urban flom. Intensjonen har vært å ta i bruk teknikker fra andre fagområder som kan føre til mer tverrfaglig samarbeid og skape mer oppmerksomhet om disse utfordringene. Forhåpentligvis kan dette arbeidet bidra til innovative prosesser. Det kan igjen bidra til å forsere overgangen til mer fleksible og bærekraftige metoder for å redusere risikoen for urban flom.

Acknowledgements

The decision to start this PhD-work was made late 2011. From then until today, it has been a long journey including a lot of interesting and hard work. As expected I have learned a lesson or two during these years, not at least that research often takes longer time than expected.

Thanks to the management and colleagues at Østfold University College, Faculty of Engineering, who believed in my project, and eased my teaching workload so that I could be a part-time PhD-student.

Fortunately, I have not made this PhD-journey all alone. There are several, helpful people who have cheered me up and supported me during these years:

Firstly, I want to thank my main supervisor, Associated Professor Jarle T. Bjerkholt at NMBU, who has been a helpful, constructive and interesting discussion partner. Even though we live at opposite sides of the Oslofjord, we have had regular meetings and phone conversations. He has continuously looked for improvements and helped me to see the big picture of my work.

Secondly, thanks to my co-supervisor, Professor Oddvar G. Lindholm at NMBU, who fortunately has had no time to retire yet. For decades, he has been, and still are, one of the most important voices in the Norwegian water and wastewater sector. I am grateful that he has been a member of my supervisor team, and helped me in my progress by supportive feedback and providing quick responses to my questions.

My other co-supervisor, Professor Ståle Navrud at NMBU, has with patience and vast knowledge, introduced me to the socio-economic field. In my opinion, our collaboration is an example of the holistic and interdisciplinary approach, which I frequently in this work has highlighted as important when dealing with the urban flood issue. Hopefully, our two disciplines will be linked even closer in the forthcoming years.

I also want to extend my thanks to Professor Knut Kvaal at NMBU who has been important to me and my work, but not been my formal supervisor. He has introduced me to the world of multivariate statistics, of which I am sure I had not dared to enter without him. With his good pedagogical skills and curiosity for interdisciplinary collaboration, we have had many valuable meetings and discussions.

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Finally, my biggest thanks go to my dear Ingeborg and our four children Ingvild, Nora, Jakob and Aksel. Extensive thanks for your support and patience during all these years.

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List of Acronyms

CBA	Cost-Benefit Analysis
cdf	Cumulative density function
CC	climate change
CV	Contingent Valuation
DEM	Digital elevation models
F	Flooded (address)
FFPI	Flash Flood Potential Index
GIS	Geographic information system
IPCC	Intergovernmental Panel on Climate Change
NOK	Norwegian Kroner
OLS	Ordinary Least Squares (Regression Method)
PC	Principal Component
PCA	Principal Component Analysis
PLS	Partial Least Squares (PLS Regression)
PLS-DA	Partial Least Squares – Discriminant Analysis
pr	probability
R	Random (randomly selected address)
SD	Standard Deviation
SUDS	Sustainable Urban Drainage System
WTP	Willingness to Pay
wtpA	Willingness to Pay for scenario A
wtpB	Willingness to Pay for scenario B
wtpAB	wtpA-wtpB

List of Publications

The following appended papers are integrated in this work:

Paper I

Geir Torgersen, Jarle T. Bjerkholt and Oddvar G. Lindholm (2014)
Addressing Flooding and SuDS when Improving Drainage and Sewerage Systems – A Comparative Study of Selected Scandinavian Cities

Water **2014**, 6, 839-857; doi:10.3390/w6040839

Paper II

Geir Torgersen, Jarle T. Bjerkholt, Knut Kvaal and Oddvar G. Lindholm (2015)
Correlation between extreme rainfall and insurance claims due to urban flooding – case study Fredrikstad, Norway

Journal of Urban and Environmental Engineering, v.9, n.2, p 127-138
doi:10.4090/juee.2015.v9n2127138

Paper III

Geir Torgersen, Jan Ketil Rød, Knut Kvaal, Jarle T. Bjerkholt and Oddvar G. Lindholm (2017)
Evaluating Flood Exposure for Properties in Urban Areas Using a Multivariate Modelling Technique

Water **2017**, 9, 318; doi:10.3390/w9050318

Paper IV

Geir Torgersen and Ståle Navrud
Singing in the rain: Valuing the economic benefits of avoiding insecurity from urban flooding

Submitted to Journal of Flood Risk Management

1 Introduction

1.1 The increasing urban stormwater challenge

Statistics show that there is an increasing trend in urban floods worldwide. Among numerous examples of extreme events in recent years are: Tokyo (2005), Sao Paulo (2008), Copenhagen (2010, 2011, 2014), New York (2012), Queensland (2010), Nairobi (2015) and the French Riviera (2015). The total economic losses due to flooding in the UK during the summer of 2007, was estimated to approximately £4 billion (€6,9 billion 2015) (Chatterton et al., 2010). In Copenhagen an extreme rain event, lasting less than three hours 2 July 2011, caused floods with damages worth more than 6 billion Danish Kroner (€0.85 billon 2015) (Rasmussen, 2014). Almost all cities and urban areas annually experience some kind of flood events. Often only single houses or small neighbourhoods are affected. These floods are typically induced by a complex set of causes. Even though each flood event in urban areas may cause small damages, they occur frequently and thus can cause high aggregated costs to society (Dawson et al., 2008). In the UK only, 16 000 properties are at risk of sewer flooding in the course of a decade. In UK these floods, caused by short-duration events, could increase from 200,000 today to 700,000 – 900,000 in 2080 (Government UK, 2004).

Researchers worldwide agree that the increased frequency of extreme weather is due to global warming and climatic change (CC). Regardless of floods, all human beings can by their behaviour contribute to reduce the negative impacts of CC. Anyway, at a local level we have to deal with fluctuating weather at any time. Carefully planned and effective drainage systems will obviously be of great importance for the impact of floods. Thus, CC should neither be the only explanation for the increased number of urban floods nor an excuse to refrain from taking preventive action at a local level. Besides extreme weather events, rapid urbanisation and wrongly designed or undersized sewers are considered to be the most important factors for the increasing urban flood events (Nie et al., 2009).

As more people want to live in urban areas, more land has to be transformed from its natural site. For the first time in human history, more than half the world's population now live in urban areas. This is expected to further increase to 70% within 2050 (Jha et al., 2012). At a local level, there are both environmental and socio-economic reasons for utilizing existing space and infrastructure to settle more people. Both in the vocabulary of politicians and urban planners the term *urban densification* is often interpreted in positive manner. However, urban densification often leads to more roofs and other sealed surfaces, which gives less opportunity to accumulate and infiltrate water. Thus, from a flood-researcher's perspective the term *urban densification* should be associated with increased potential for flooding.

In Europe, municipalities often own and operate the sewer systems in urban areas. The decades before the 1960s the sewer systems were build out in most cities, and the main technical solution was to collect and transport stormwater and sewerage from households in one single pipe (combined system). Since the late 1960s, two-piped systems (separate system), one for sewer and another for drainage water has been the standard method. Normally, the life expectancy of sewer systems is one hundred years or more. Therefore, and due to considerable replacement costs, downtown areas in most European cities will have a large number of combined systems for many years to come. Conventional piped drainage systems are designed for a specific maximum flow rates and will be unable to meet the expected increased volume of water (Sharma, 2008). In Norway more than half of the systems (by pipe length) are built before 1980 (SSB, 2012), and the oldest systems are found in the city centres. The current pipes in the drainage systems in Norway cannot easily be replaced by larger ones (Lindholm and Bjerkholt, 2010). Increased rainfall will be an additional challenge for the transportation system in addition to lack of maintenance and malfunctions caused by aging (Carrico et al., 2012).

Extreme rain and flooding in cities have large social costs such as traffic disruptions, damage to infrastructure and buildings, people experiencing uncertainty for new floods, sick leave due to infectious water, lost sales for businesses, pollution of drinking water and local recipients (Lindholm et al., 2008). Insurance companies in Norway estimated in 2007 that the costs of urban flooding in Norway could increase by 40% or more over the next ten years (Nyeggen, 2007). Adjusted for inflation, the overall cost for damages due to precipitation during 2012-2014 has proven to be 46% higher compared to 2008-2010 (Finance Norway, 2017b).

The complex nature of flooding and how to prevent or mitigate it, makes decision making in this area difficult. Expertise, time, economy, traffic and development of other infrastructure need to be coordinated. Given the complexity, it is a challenge to maintain a holistic perspective in the process of taking good decisions for efficient solutions.

Climate change, as well as population growth and densification, are significant drivers for developing a more sustainable stormwater management to avoid adverse effects of urban floods. However, these challenges may also imply an opportunity to push the sustainable development forward (Cettner, 2012, Faram et al., 2010, Chocat et al., 2007, Marsalek and Chocat, 2002). The water and wastewater sector is considered to be a very conservative one (Aall et al., 2011, Harremoes, 2002), and the engineering culture is often referred to as a key barrier to implementing sustainable approaches in practice (Harremoes, 2002, Bos and Brown, 2012). It was also referred to as: *'Professionals were professionally prepared, but not sufficiently practically prepared for action'* (Cettner et al., 2014, p.39). Among others, they emphasized increased awareness and simplicity, clarity of goals and priorities to ensure more sustainable solutions in practice. Fraser et al. (2006) pointed to the importance of having processes that allow citizens to be actively involved in this issue. Such processes will strengthen decision makers struggling to find sustainable pathways.

1.2 Urban flooding – refinement of the concept

Urban floods can be divided into several types. Basically, the source of floods in urban areas can be overflowed rivers, tidal water, ground water, snow melt or heavy rainfall exceeding the capacity of the drainage and sewer systems (Jha et al., 2012). However, the research informing this understanding of the concept of flooding has been restricted to the most frequent type of urban floods, the one induced by heavy rainfall. This is also known as *pluvial floods*, as opposed to *fluvial floods*, which are strongly related to overflowed rivers.

Although urban floods can be categorized by e.g. source, duration, impact or responsibility, there is no absolute definition of this concept.

Urban areas are subjected to the same hydraulic laws as the natural environment, but human activity enhances the factors affecting flooding. Additionally, in contrast to the countryside, urban areas have more people and assets gathered within a smaller area, and thus, floods cause a higher cost to society.

The duration of heavy rain causing floods can be from minutes to several days, but usually it lasts for a few hours. Almost immediately, this rain can cause flooding in urban areas. Moreover, cities often have limited space for temporary storage of water and thus flooding is inevitable. For single houses, the impact of heavy rain can be from moisture in certain basements to destroyed buildings in need of reconstruction. According to Finance Norway (2017b) the cause of floods in buildings is often associated with surcharges of the main pipe system or surface flow due to limitation or failure in the drainage and sewer systems.

The concept of *urban floods*, as it is understood in this study, will rarely cause a direct threat to life. Therefore, it could be argued that it would have been more appropriate to use the weaker term *inundation*. Nevertheless, damages limited to financial losses and reduced quality of life can be a significant problem for affected people.

1.3 Main objectives / research questions

The overall purpose of this study is to provide empirical and theoretical evidence which may contribute to reducing the impact of urban floods caused by heavy rainfall and based on both own surveys and available statistical data. It is believed that this challenge is best met with an interdisciplinary and holistic approach.

Given the expected increase in flood events in the coming decades, the main objectives throughout this work have been to:

- implement knowledge and methods from non-engineering disciplines, with an intention to create more public engagement and awareness of the urban flood issue
- develop innovative tools to complement traditional engineering based approaches, which can contribute to and accelerate the process of achieving a more sustainable stormwater practice

The results of this work are presented in four research papers. The work presented in Paper I was based on empirical data related to measures carried out in practice. A main focus in this paper was the question of how professionals rank preventive measures against urban flooding compared to other possible objectives. This study also investigated if municipalities took on more innovative techniques in their renewal work versus the use of traditional approaches. The work presented in Paper I formed the basis for the subsequent work as it put priorities and implementing measures up against other objectives to improve the drainage and sewer systems. In Papers II, III and IV new tools were introduced, all related to urban stormwater management. Their common emphasis was the inclusion of statistical analysis based on users' experiences. An overview of the more detailed research questions, Types of data analysed and aims are shown in Table 1:

Table 1: *Overview of research questions and aim*

Paper	Focus	Research question	Empiri	Aim
I	Review urban flood focus in Norway and Scandinavia.	How is flood prevention and SUDS focused when Norwegian cities improve their drainage and sewer systems? Are there any differences among Scandinavian countries in how the cities or the national authorities meet this issue?	A survey among the largest cities in Scandinavia. Extraction of data from national registers.	Investigate the state-of-the-art regarding urban flood management in Scandinavian cities. Examine any differences across the countries and give possible explanation for that.
II	This study highlights the main hazard to urban floods, which is extreme rainfall.	Are there characteristic fluctuations in short and long term rainfall, which affect insurance claims due to flooding?	Damage data and corresponding rainfall data in a given case area.	Identify correlation between claims and rainfall data and discuss possible explanation for that.
III	This study focuses on a building's exposure to urban floods by analysing variables associated with terrain data.	When it comes to location, are there any characteristics for houses affected by floods compared to non-flooded?	Damage data and randomized addresses in a given case area. Corresponding number of terrain variables (slope, curvature etc.)	Reveal patterns and correlation between terrain parameters and the impact of flooding. Furthermore, give possible explanation for the findings.
IV	Insecurity to floods represents a welfare loss for some people. This study focuses on estimation of households´ willingness-to-pay (WTP) for security to urban floods.	Are there any variables significantly affecting the willingness to pay to avoid urban floods? Is it possible to estimate insecurity of flooding in monetary terms and to specify an insecurity cost?	Survey data showing i.a. non-market goods valuation, such as insecurity.	Find significant variables which seem to have an impact on the insecurity to urban floods. Valuate individuals' insecurity to urban floods in monetary terms.

1.4 Structure of this work

The first part of this study can be regarded as an introductory section to the four papers that constitute the PhD-work and summarises and compares the shorter works in an overall perspective. This section is structured as follows:

Chapter 1 is a brief introduction to make the urban flood issue topical. It explains how the concept of urban floods is understood in this work. The main objectives and research questions for this particular work are presented.

In Chapter 2, recent perspectives on stormwater management in general, and urban flood in particular, are presented as a backdrop. This is essential, as the need for more sustainable planning and an interdisciplinary approach to urban floods is grounded in the ongoing development in this field. Papers II, III and IV can be put into a conceptual framework called the Risk Triangle (Crichton, 1999) with three key-elements named: *Hazard*, *Exposure* and *Vulnerability*. This framework is presented in Chapter 2. Altogether, they constitute the risk for urban floods, (see Figure 1). Preventive measures, aiming to reduce the impact from one of these key-elements, will contribute positively to reducing the risk of urban floods.

In Figure 1 an interrelation between the various parts of this work are illustrated.

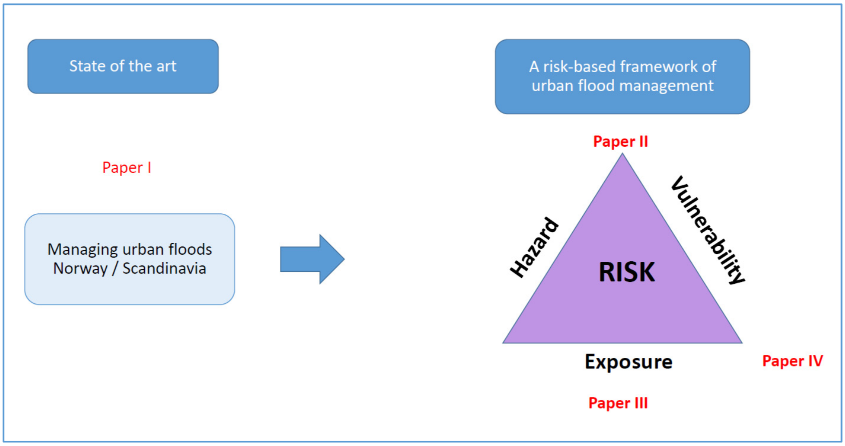

Figure 1: *Interrelation of the papers (adapted from Crichton, 1999)*

Chapter 3 covers methods and materials used in this work. Several statistical methods were applied throughout this work, and thus a brief description is given. Additionally, empirical data for the different papers are specified.

A presentation of the results and discussions are to be found in Chapter 4. As seen in Figure 1, there are different pathways aiming to reach the ultimate goal, i.e. reducing the impact of urban floods. The three last papers can be regarded as separate examples of possible pathways to reduce the risk. At the same time, there are commonalities in the mindset behind the methods used across the papers. One of them is to introduce new tools, which can lead to increased awareness of this issue. Finally in this chapter, the findings in each papers are summarised.

In the conclusions in Chapter 5, the main foci and findings in the four papers are seen in relation to each other, and corresponding conclusions are drawn. Referring to the main objectives, the idea behind this investigation has been to introduce new planning tools. In this chapter the potential for generalizing the findings to contexts beyond the study are discussed and related to the backdrop mentioned in Chapter 2 and the question of how urban flood reduction can be achieved in general.

2 Current perspectives in urban flood management

2.1 Sustainable planning of urban stormwater systems

Sustainable planning of drainage systems covers a range of management practices designed to accommodate the drainage of surface water, as it more closely resembles the runoff from a natural site (Fletcher et al., 2015, DEFRA, 2005). The need for sustainable drainage systems is closely related to urban and built-up areas, as the possibility of natural runoff here is often limited compared to rural areas. This concept has been named Sustainable Urban Drainage System (SUDS) and is considered as a necessary step to accommodate an expected increase in urban runoff (Kennedy & Lewis, 2007, Semadeni-Davies et al., 2008b).

2.1.1 Sustainable urban drainage system (SUDS)

SUDS measures aim to reduce the adverse influence of surface water in urban areas by non-piped solutions, often by infiltration or using the surface for temporary storage or transportation of water. Ponds, open ditches, green roofs etc., are examples of solutions in line with the SUDS-concept. In some countries they are made for stormwater treatment, but in urban areas in Scandinavia the authorities have only to a small extent required stormwater treatment, and SUDS has then largely been considered as a flood prevention measure e.g. in Malmö, Sweden (Villarreal et al., 2004).

Municipalities in all Scandinavian countries have been encouraged by the national authorities to increase the use of SUDS for decades. (SFT, 1982, VAV, 1983, Anthonisen et al., 1992). Several studies (e.g. O'Sullivan et al., 2012, Cettner, 2012, Ashley et al., 2011) concluded that although the benefits of SUDS are obvious, they are not sufficiently appreciated.

2.1.2 Regime shift towards SUDS

Within urban stormwater management, like many other fields, a dominating way to solve a social challenge can be denoted as regime, and such a regime is typical for the way we meet needs in society (de Haan and Rotmans, 2011). Other regimes, which have power, are frequently referred to as niche-regimes, although they are not dominating the way that the societal needs are met. Niche-regimes fundamentally challenge the dominant regime. A change in which a niche-regime emerges, and finally oust the dominant regime, may occur. The dominant regime will be at any time what protects the society's needs in the best way. This transitional change is denoted regime shift.

According to Ashley et al. (2011) the societal system is composed of a number of societal subsystems, and stormwater management in cities is an example of this. Today, the stormwater issue in cities, deals with two fundamentally different competing regimes. The old regime, which in most cases also is the current regime, is still to improve the system through piped solutions. Changes in boundary conditions (e.g. more flooding, as a consequence of climate changes) may change the society’s opinion and help the niche to develop. However, a sudden increase in flooding events may be met by decision makers seeking conventional renewing methods, because there is no time for untested methods like SUDS. Thus, the uptake of this niche may be delayed. However, the development of SUDS has been accompanied by an increasing focus on the possible impact of climate changes (Semadeni-Davies et al., 2008a). It is then assumed that a transition towards the new regime for stormwater management will accelerate.

A general model (de Haan and Rotmans, 2011), adapted by Ashley et al. (2011), has further been simplified in this study in order to describe the increased attention to reduce flooding as a target and SUDS as a preferred method. This is illustrated in Figure 2 as a transition line between the old and the new regime.

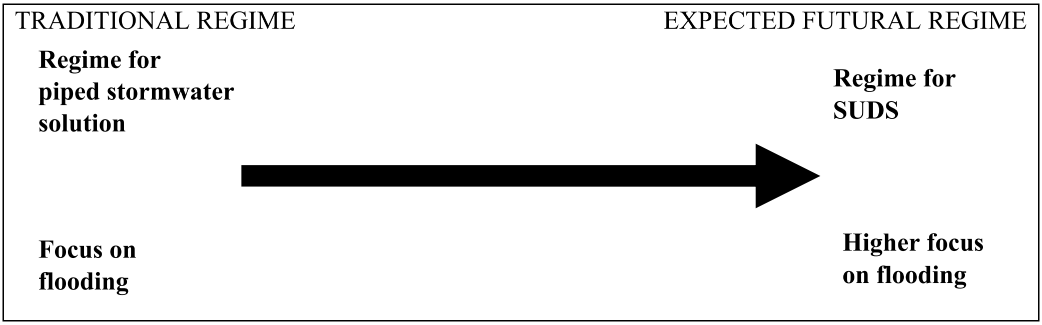

Figure 2: *Transition line toward a SUDS-focused regime*

According to Geels (2006), the conceptual characteristics of a regime transformation is that the regime insiders gradually change their cognitive beliefs and behavioural norms. In this context, changing people's thinking is becoming at least as important as gaining new scientific understanding (Douglas, 2000).

2.1.3 SUDS as a flexible approach to future uncertainties

When initiating preventive flood measures, it is crucial to use knowledge updated for relevant future conditions, considering the amount of rainfall, frequency, population growth etc. When a decision is taken, there will always be a risk of building constructions that are too small, with the consequence that reinvestments or supplementary measures to increase capacity are needed. Conversely, by building too large one risks attracting criticisms of overinvestment, wasting money that could have been used for other purposes.

Assessments are fundamentally a 'struggle against the forces of nature'. Nobody knows for sure what will actually be dimensioned rainfall amounts in the future. The construction or upgrading of drainage and sewer systems are often both time-consuming and capital intensive, and it is expected that the piped system should work for at least 100 years until replacement. Which loads the system then will then be exposed to, is highly uncertain. The Intergovernmental Panel on Climate Change (IPCC) highlights this in the foreword of the report from 2012 as *'This Special Report, in particular, contributes to frame the challenge of dealing with extreme weather and climate events as an issue in decision making under uncertainty'* (IPCC, 2012, p. viii). A study from Belgium showed that the increase in daily summer rainfall extremes may vary from -17% to + 12% by 2100 (Willems, 2012, Ntegeka et al., 2008). Both urbanization and population growth will affect the run-off both with respect to sealed areas and the route of flow water. Studies from Belgium, Canada, Italy and Australia all have errors up to 40% by comparing historical rain data and sewer flows. Nie et al. (2009) found that in relation to increased rainfall, water spills from manholes increased 2-4 times and similarly the CSO volume was 1.5-3 times.

The uncertainties should not be an argument for delaying investigations or modifying measures. According to Willems (2012), as the CC occurs gradually, there is no need to invest heavily today in upgrading all infrastructure soon. Instead, we should account for uncertainties by using more flexible and sustainable solutions (Refsgaard et al., 2013). An adaptive approach can be established which means both flexibility and reversibility. This is different from the traditional engineering approach, which is regarded as more static and often based on design rules set by engineers without much public debate (Arnbjerg-Nielsen et al., 2013).

To assess the risks and uncertainties associated with flooding, a gradual expansion is made as a scenario tree, seen in Figure 3. This is adapted from a general model shown in Boardman (2011) and Gersonius et al. (2013) for assessment of flood risk. When planning projects, it may be appropriate to focus on maintaining the flexibility of a development rather than postponing projects. In particular, two mechanisms can provide flexibility value. Firstly, one can start with a less costly development. Secondly, a gradual expansion based on acquired experiences can make it possible to adjust the project at later stages. For example, changing climate scenarios result in adjusted design criteria both based on new forecasts and changes in operating experiences.

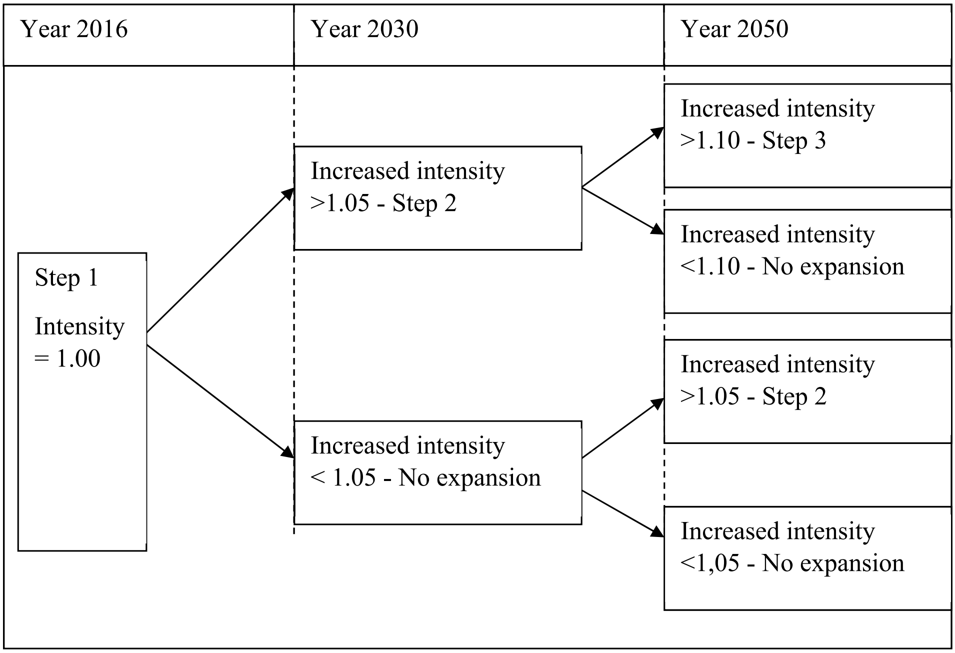

Figure 3: *Scenario tree (adapted from Boardman, 2011, Gersonius et al., 2013)*

According to socio-economic theory, the use of adjustable measures are likely to be more beneficial, socially and economically, than the use of measures that are more fixed. Flexible design can be regarded as a real option that are considered to be a possibility, that is a right, but no obligation to act in the future (Dixit and Pindyck, 1995). Real Option Theory, is all about valuing flexibility in areas of uncertainty and irreversible decisions and has rarely been used in Norway (Sødal, 2005). Thus, the theory may be relevant for prevention projects. Flexibility in planning, including stepwise development or delayed start up, are highly likely to be profitable. Real options can sometimes be difficult to value accurately. According to Amram and Kulatilaka (1999) real options are very much about mindset. Gersonius et al. (2013) point out that real options when renewing infrastructure (such as drainage and sewer systems), are different from traditional real options theory that is often all about making an investment immediately or in the future. However, similarities between financial market interventions and the decisions required for major infrastructure investments, point to the relevance of applying a model from financial options analysis in the analysis of flooding.

The transition towards more SUDS could be seen as a sustainable adaptation to future scenarios where there currently are uncertain prognoses. They can be decided reactively, with short-term perspectives and localised effects, and they are relatively cheap. Since this also largely includes 'surface solutions' it is easier to make stepwise developments over time, based on new events and scenarios. Sustainable water management requires actions, measures and designs that are climate-resilient, which we will not regret in the future. Solutions or measures for adaption should indeed be robust and able to cope with a variety of future changes. A consequence of a 'non-regret'-approach, is that measures should be potentially irreversible or in worst case rejected if new knowledge appears. This approach is believed to be challenging, especially for professionals as it differs from the traditional mindset by delivering complete future-oriented solutions. (Willems, 2012, Ashley et al., 2008).

However, no kind of measures can be regarded as stand-alone solutions. An adaptive strategy will often include infrastructure investments. (Refsgaard et al., 2013). Simultaneous modelling of different future scenarios and possible measures can be useful tools to determine whether such a stepwise approach is expedient and profitable. Because this is a field without exact solutions and with uncertain challenges, the word *flexibility* should be regarded as a keyword. Flexibility can then be seen as another advantage of implementing SUDS.

2.2 An interdisciplinary approach – to reduce flooding

Traditionally, planning and development of measures to prevent flooding in cities in Norway, Scandinavia and Western Europe has been a municipal engineering discipline. Even though there has been some progress, several studies regarding sosio-technical processes, clearly confirm the slow pace and lack of innovation related to urban flood management (e.g. Cettner et al., 2012, Bos and Brown, 2012, Ashley et al., 2011, Brown et al., 2006). Wong and Eadie (2000) also sum this up in a critical review, stating that the traditional approach has been '*Stormwater management should be left to engineers, or wetland design should be left to landscape architects'*.

It is expected that the SUDS approach to urban flood management both literally and metaphorically will be 'brought to the surface'. In itself, this can attract more non-engineers into this field as it will become more visible and not unilaterally a technical issue of piped system below the ground. A number of research projects in the recent decade highlight the importance of an interdisciplinary approach to the urban flood issue (Bos and Brown, 2012, Ashley et al., 2011, Tippett and Griffiths, 2007, Fraser et al., 2006, Harremoës, 2003, Wong and Eadie, 2000, Braga, 1999).

Catchment area has turned up to be an important unit to integrate e.g. land use planning and water management. This understanding has later been extended to urban areas where the impact of the water flow through the landscape might be less obvious (Tippett and Griffiths, 2007). Hydraulic capacity of pipes should not any longer be the defining criterion when designing urban drainage system. Information about the possible causes and effects of flooding of the urban environment can be presented in a clear manner on a multi-layer map, where different aspects from several disciplines are combined. This combination of information could lead to a better understanding of the mechanisms and how to take precautionary measures against flooding (van Luijtelaar et al., 2008).

Professionals such as landscape planners, municipal officers, water-engineers, developers, road-planners, emergency departments, sociologists etc., can all make important contributions to the field of urban flood management based on their expertise. By drawing on data and analyses from computer scientists, statisticians, geomaticians etc. it is possible to derive and view relationships that were previously not known.

As even more citizens will be affected by floods, public awareness is expected to increase. The choice of decentralized solutions to prevent floods will further directly involve local communities or single households. The involvement of citizens in a so-called ‘bottom-up’ process, and in such a way that they can choose indicators, has proven to be valuable. (Fraser et al., 2006).

Environmental managers and policy-makers need tools to bring together local community input alongside with experts to measure the impact of policies and management plans. In other words, both experts from several disciplines, local knowledge and practical experience from citizens affected, are essential instruments and a prerequisite for an accelerated development of SUDS. Traditionally, development of environmental plans has been performed by experts with limited local knowledge or support among ordinary citizens for strategic decisions. Data has to be collected and made available at the smallest possible scale, and aggregated into a larger planning unit using a transparent process. Participation in decision making and development of a shared understanding of problems and options, may increase the likelihood of changing behaviour concerning flood mitigation (Fraser et al., 2006, Chocat et al., 2007). As a result, decision makers need tools to get the community involved and to draw on expert advice in order to develop strategies and management plans. This can further provide databases that reflect local values, and on the basis of those databases decisions can be made.

2.3 A risk-based framework to urban flood management

During the last decades worldwide there has been a move from strategy of flood defence to flood risk management (Butler and Pidgeon, 2011, Gouldby and Samuels, 2005). The UK made, after having experienced recurring flood events, a new strategy for dealing with floods called ‘making space for water –strategy’ (DEFRA, 2005). This calls for a more holistic approach when managing water and include simultaneously managing the impact of floods as well as reducing the probability. This also implies that accepting and making preparations for floods will be more effective from both financial, socio economic and environmental perspectives (Zevenbergen et al., 2007).

The shifted flood approach from defence to risk management has also brought more ‘soft-engineering’ skills into light. This change can be seen as a change in understanding, in the sense that floods are expected to happen, and that some traditional hard engineered solutions are not flexible enough to cope with uncertainty and may fail when they are challenged (Tippett and Griffiths, 2007).

In its simplest form, probabilistic risk assessment defines the risk as:

$$Risk\ = f(probability, consequence)\ [1]$$

Equation [1] represents a quantitative definition of risk. As mentioned a wide range of factors influences the outcome of extreme events in urban area, including climate effects, urbanization and the ability to cope with floods. However, a qualitative risk approach might be preferred if one wants to view risk as an interaction between the hazard, the exposure and the vulnerability to floods.

$$Risk = f\ (hazard, exposure, vulnerability)\ [2]$$

Hazard

In IPCC (2012, p. 560) hazard is defined as the *'potential occurrence of a natural or human-induced physical event that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, and environmental resources'.* However, according to Crichton (1999), and in this context, it is characterized as *'A potential cause of loss and not the loss itself'*. Restricted to urban floods, hazard represents the frequency and severity of rainfall events or storms. Predicted climate change is obviously leading to increasing hazard. Anyway, the local community has little immediate control, except clearing the watercourses, providing adequate drainage, and preparing for extensive flood drainage in the natural way. As urban floods are mainly caused by short duration rainfall, it might be hard to forecast and warn against the hazard. (Crichton, 2012, Kaźmierczak and Cavan, 2011).

Exposure

According to IPCC (2012, p. 32) exposure refers to the *'presence (location) of people, livelihoods, environmental services and resources, infrastructure, or economic, social, or cultural assets in places that could be adversely affected by physical events and which, thereby, are subject to potential future harm, loss, or damage'*. In an urban flood context, intuitively downtown and low-lying areas along hillsides should be more exposed than more elevated areas. However, there might be more local differences within neighbourhoods depending on distance to paved areas, sewer system, watercourses etc. As a consequence of population growth, more natural land will be transformed into urban areas (Kaźmierczak and Cavan, 2011). It is reasonable to assume that this will lead to even more people being exposed to urban flooding.

Vulnerability

Several reports and papers through the last decade have presented different definitions of vulnerability to floods (IPCC, 2012, Kaźmierczak and Cavan, 2011, DEFRA, 2006, Wisner, 2004). One is *'propensity or predisposition to be adversely affected' (IPCC, 2012, p. 564) and 'ability to respond to a flood by being able to physically withstand the flood water's velocity and depth'* (Kaźmierczak and Cavan, 2011, p.186). Vulnerability to people can simply be understood as their ability to physically cope with and withstand the flood. In a broader sense, this can be regarded as a function of e.g. historical, political, economic, social cultural dimensions. Kaźmierczak and Cavan (2011) link vulnerability to four dimensions: access to information, ability to prepare for, respond to, and recover from flooding. Vulnerability should not only be restricted directly to a human dimension, one should also acknowledge that building standard and design of properties play an important role.

Risk based approach to urban flooding

Usually, technical risk analyses have been associated with probabilities. Despite the simplicity of Equation [1] in its pure form, there is a huge number of relevant variables, which are hard to measure. Thus, for practical purposes it is difficult to make a comprehensive quantitative probabilistic risk analysis for urban flooding.

As mentioned, disaster risk management as well as adaptation to climate change now emphasize a more holistic, integrated, interdisciplinary approach. Interdisciplinary approaches have to take different scientific languages into account (Munda, 2003). Regarding urban floods, risk management have to cover both 'harder' values such as physical and material events, as well as 'softer' ones like insecurity and stress. (IPCC, 2012). Thus, Equation [2] represents a qualitative approach, which is more widely used when aiming for reducing the impact caused by weather extremes.

The three key elements described above can all be considered as integrated parts of risk management to urban floods. Figure 3 views these elements as they were originally presented as an approach to risk management for the insurance sector (Crichton, 1999). Later this is widely adopted and used in reports related to CC and specific articles in urban flooding (e.g. IPCC, 2012, Kaźmierczak and Cavan, 2011, Lindley et al., 2006).

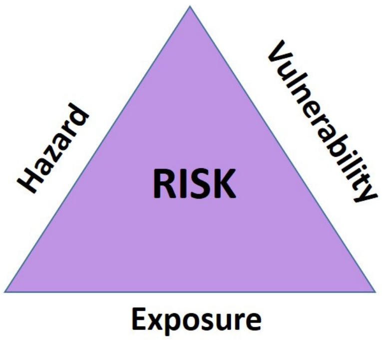

Figure 4: *The Risk Triangle (Crichton, 1999)*

For risks to be realised, there must be a spatial coincidence of both the hazard and vulnerable elements within an exposed area to the hazard. (Lindley et al., 2006). According to IPCC (2012) it is a common understanding that high vulnerability and exposure are often results of a failed community development process, associated with environmental mismanagement, population growth, rapid and unplanned urbanization, and limited options for the most vulnerable citizens.

From the triangle in Figure 4, there are several possible 'points of attack'. As we will see in the following sections, the different papers 'attack' this issue in slightly different ways.

2.4 Approach to the urban flood challenge in Scandinavia the recent years

Several international publications and guidelines related to urban flood management have been published since the millennium. The most recent, comprehensive, international reports applied for this work are *'Cities and flooding: a guide to integrated urban flood risk management for the 21st century'* (Jha et al., 2012) and *'Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation'* (IPCC, 2012).

In Norway in December 2015, a committee appointed by the government delivered a report concerning regulations for urban stormwater management (Government N, 2015). Initially they conducted a survey among municipalities, which revealed that although the potential threat posed by urban stormwater challenges were well known, municipalities reported lack of competence and funding to handle this issue. The main objective of the governmental report was to develop and assess regulations regarding the urban stormwater management. The committee argued that responsibility for urban flood management must be managed at a local level, and pointed to the municipalities as the most obvious actor to coordinate this. The report recommended the introduction of a new municipal fee, based on the amount of water drained from the properties. This will, among other things, finance stormwater installations in public areas. However, the committee was not unanimous in its recommendations regarding issues such as the assignment of responsibility for flood management (except extraordinary events). Early 2017 it is unknown when this report will be further processed in the Norwegian Parliament.

Currently there is a general perception that there will be more frequent flooding in the future and that SUDS is the most sustainable approach to reduce the risk. Several publications in recent years related to this issue, therefore deal with societal aspects (responsibility for preventive measures, how to get more public awareness, how to implement sustainable measures more rapidly etc.) rather than technical solutions. Despite this, as indicated in the findings in Paper 1, supported by surveys and studies mentioned above (Cettner et al., 2014, Government N, 2015) the transition towards a more sustainable stormwater practice seems to be slow. In general, this area is still regarded as a municipal engineering discipline.

3 Methods and Materials

3.1 Statistical tools (Papers II-IV)

Traditionally, hydraulic modelling has been used to identify and verify problems and as a tool to plan improvements regarding urban flooding. By using calibrated dynamic models, it is possible to simulate whether a system has sufficient capacity or not, and how changes to the geometry of the system will affect functionality.

The main objective of this work has been to develop innovative tools that can complement traditional methods for handling urban flooding by drawing on knowledge from other fields.

An additional purpose has been to raise awareness of the urban flood challenge, using statistical data based on flood damaged houses, as well data gathered on the basis of people's flood experiences in order to capture public interest, Finally, several analyses of a wide range of relevant data, illustrate the diversity of 'points of attack' aiming to reduce urban floods.

The software *Unscrambler®* version 10.3 was used for the Principle Component Analysis as well as Partial Least Squares Regression (Camo, 2015), respectively in Paper II and Paper III. Further, the software R (Venables et al., 2009) was used for Ordinary Least Squares and Probit-model in Paper IV with the interface of *R-studio* (RStudio Team, 2015).

3.1.1 Using Principle Component Analysis (Paper II)

The goal of Paper II was to investigate the relation between damage cost and heavy rain on different temporal scales. The investigation of rainfall and corresponding cost of urban floods is based on analyses of several different parameters. The dataset in this case was extracted from the database of the insurance companies and meteorological data from the city of Fredrikstad in Norway. Even though there are a number of parameters that seem to have an impact on urban flooding, this study was limited to patterns between registered claims and rainfall characteristics.

In this investigation, *Principal Component Analysis (PCA)* was utilized. PCA is a multivariate tool and an alternative statistical method for explorative data analysis and one of the most widely used multivariate techniques in statistics. (Jackson, 1991, Jolliffe, 2002, Mardia, 1979, Hardle and Simar, 2007, Reris and Brooks, 2015). Even though the method has proven to be beneficial in several fields (chemometrics, econometrics etc.) because of its ability to simplify complex datasets, the use of PCA for the analysis of urban flooding is limited.

PCA was found to be a suitable tool for analysing a set of multivariate and intercorrelated data. Furthermore, the idea was to develop an interpretable model and identify patterns among variables.

In PCA the dimensionality of a dataset with several variables is reduced to fewer latent variables, which are denoted as principal components (PCs). The PCs will often be interpreted as phenomena or describe a behaviour in the dataset.

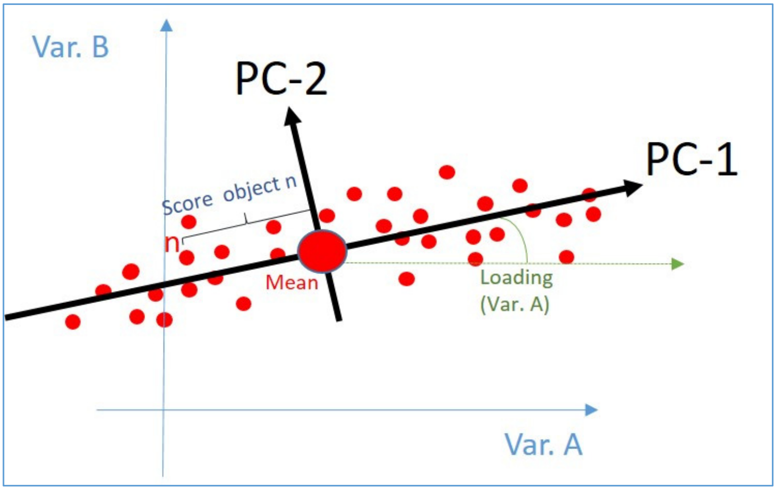

Figure 5: *Principles of dimension reduction into Principal Components and scores and loadings*

Figure 5 illustrates principal components, in a dataset with only two variables (Var. A and Var. B). The first principal component accounts for the maximum proportion of variance from the original dataset. The remaining variance, which is not captured by PC-1, is described by PC-2. All principal components form a new orthogonal coordinate system that best describes the total variance of the dataset in each principal direction. The samples can be associated as scores in the space spanned by PC-1 and PC-2. The variables that contribute to the corresponding PCs, are expressed as loadings.

Normally the number of variables are far more than two, as shown in Figure 5. Then the values of scores and loadings are calculated and viewed separately in a score and loading plot. However, for interpretation, these plots should be displayed simultaneously, as seen in Figure 4 in Paper II. If sample *n* is plotted to the far right in the score plot, this sample usually has high value of variable *m*, if *m* in the loading plot is placed to the far right as well. It is then possible to view underlying structures in the data, which are not observed in a univariate tool (Esbensen et al., 2000, Kaźmierczak and Cavan, 2011).

3.1.2 Using Partial Least Squares Regression (Paper III)

The purpose of Paper III was to look for patterns between flooded and non-flooded houses and corresponding terrain and sewer data. Similar to the previous paper, the dataset was extracted from the database of the insurance companies from the city of Fredrikstad. In contrast to Paper II, this analysis was not only carried out in order to reveal patterns, but was formulated as a classification issue, modelling if an address was more likely to be flooded or not.

As a comparable independent sample of flooded addresses, a similar number of randomized objects were generated. The idea was to examine any difference between houses affected by floods and non-affected houses. It proved that 168 random addresses used in the analysis, with one exception, were non-flooded. However, the purpose of this study was to determine whether it was possible to classify an address belonging to one of the two possible outcomes (flooded/random). Independent variables (predictors) related to terrain and sewers for the affected addresses were added. All predictors (e.g. elevation, slope, upstream area) were chosen as they were considered to have an impact to urban floods.

For this study, *Partial Least Squares (PLS) Regression* was chosen. It was originally developed as a technique in econometrics, but is today primary used as a tool for chemometrics. Only occasionally, it is used in environmental studies like this one (Nash and Chaloud, 2011, Zhang et al., 2015). Its emphasis is on the prediction of responses (Y). Due to the classification issue in this case, this tool was found to be particularly suitable, and as there were only two classes of interest, a special case called Partial Least Squares – Discriminant Analysis (PLS-DA) was preferred. PLS-DA was also found appropriate, due to the high collinearity in the dataset, which may lead to poor results if using linear models (e.g. OLS regression) (Farahani et al., 2010, Tobias, 1995).

Similar to PCA, the outcome of PLS regression can be viewed as score and loading plot. The software plots each sample on a 2D map (score plot) based on calculated values related to the factors (latent variables) from the PLS regression. In the plot, Factor-1 will capture most of the variance, Factor-2, second most etc. Simultaneous interpretation of scores and loadings are probably the most useful feature of the plot. Like PCA, a sample located to the right in the score plot, usually has a large value for variables to the right in the loading plot, and vice versa. In this study, samples were labelled in the score plot, as flooded or randomized objects. By comparing score and loading plot, characteristics of the two classes could be explained (Camo, 2015).

Initially, a PLS regression starts with scaling and constructing linear combinations of the predictors (X) and responses (Y). According to the algorithm, both X and Y matrices are decomposed into matrices of scores and loadings. The decomposition process is finalized when the linear combination of the predictors reaches its maximum covariance with the responses. In general algebraic terms, this can be written as:

$$X = T\ x\ P^T + E$$

$$Y = U\ x\ Q^T + F$$

P and Q are the loadings and E and F are residuals (errors) for the X and Y matrices, respectively. The original dataset of X was regressed into t-scores T, which in turn were used to predict the u-scores U. Finally, the u-scores were used to predict the responses $\hat{Y}$.

To assess the properties for the PLS-DA model, validation was required. As the number of samples was considered to be small, a cross validation of the dataset was found to be a proper method. During the cross-validation, the dataset was divided into 20 segments. Each segment was left out from the calibration data set and the model was then calibrated for the remaining objects. Then values for the left-out objects were predicted and residuals were calculated. This process was repeated with another subset of the calibration set until all segments had been left out once (Camo, 2015).

An approach to solve classification problems is through linear regression with dummy responses (Indahl et al., 2007). This is a binary linear classification (flooded and random). The dummy matrix Y (n x 2), can be defined:

$$Y_{ki} \stackrel{\text{def}}{=} \begin{cases} 1, & y_i = member\ of\ the\ class \\ 0, & y_i = non - member\ of\ the\ class \end{cases}$$

$$i \in \{1,2 \ldots . n\}\ and\ k \in \{1,2\}$$

Furthermore, the scores from the PLS-DA were used to assign class membership for each address. As there were two classes, the original dummy values could be either 1-0 (flooded) or 0-1 (random). The model predicted two ŷ-values and $\Sigma \hat{y}_i=1$. An often used approach for assigning membership of a class, is the 'winner-takes-all-strategy' and the majority vote (Pérez et al., 2009). This means that the highest score calculated from the model obtains the class-assignment. Transferred to this study, $\hat{y}_{i,\ Flooded} > \hat{y}_{1,\ Random}$ should be interpreted as flooded and vice versa.

3.1.3 Using Ordinary Least Squares and Probit methods (Paper IV)

In Paper IV, the study was designed to measure the insecurity to urban floods, and for this study, an internet survey was conducted. The key question was to state the insecurity cost, by measuring Willingness To Pay (WTP) for two hypothetical scenarios. For this study it was not only important to estimate the WTP in order to avoid flooding, but also to examine how it varies with the respondents' age, gender, flood experience etc.

By building regression models and using WTP as the dependent variable (Y), the objective of the model was to validate the dataset and determine significant variables. The net sample consists of two almost equally sized sets of respondents stating their WTP for two scenarios, those with a positive WTP (insecurity cost >0) and zero WTP (insecurity cost =0). The majority of the positive WTPs were small values, and in linear regression, a distribution close to normal of the dependent variable is required. Thus, in a diagram, the dataset obviously would have been skewed to the left with respect to increased WTP. To deal with this, two types of regression models were created:

- Linear models (*Ordinary Least Squares OLS*) were chosen for the subset of positive WTPs to determine which independent variables that affected the valuation most. Such models are made in the following general form:

  $$y = \beta_0 + \beta_1 \times x_1 + \beta_2 \times x_2 + \ldots + \varepsilon$$

  To ensure a WTP-distribution closer to normal in the final model, the dependent variable was log-transformed.

- As it was intended to create a model for the entire sample, a binary outcome (pay something / pay nothing) was found most appropriate, due to the skewness of the responses. In a *Probit model* the dependent variable can only take two values. Two dummies were made to determine the significant independent variable. Any positive value was given the dummy value = 1, while zero WTP was denoted as 0.

Instead of estimating the y (as in a linear regression), the probability of y=1 was estimated as a function of the independent variables for a binary outcome:

$$\text{pr}\,[y = 1|\boldsymbol{x}] = F(x'\beta)$$

For the Probit model, $F(x'\beta)$ is the cumulative density function (cdf), assuming normal distribution.

$$F(x'\beta) = \Phi(x'\beta) = \int_{-\infty}^{x'\beta} \Phi(x'\beta)\, dz$$

It follows that probabilities only can take values between 0 and 1.

Before models were established, the correlation coefficients (R) between the different independent variables were calculated. According to textbooks on statistics (e.g. MacInnes, 2016), R = 0.6 is regarded as a threshold for collinearity, and exceeding this will interfere the model. As Personal income vs. Household Income had R = 0.74, one of the two variables had to be omitted from further analyses. The first one was excluded, as it in the survey was asked for WTP for the household.

3.1.4 Summarising statistical tools

Finally, the dataset in Papers II-IV consisted of:

Table 2: *Summarising main statistical tools and software*

Paper	Statistical tools	Software	Objective of selected statistical models
II	Principal Component Analysis (PCA)	Unscrambler ®	Reducing dimensionality, to detect phenomena (Cost of flood vs. rainfall)
III	Partial Least Squares– Discriminant Analyses (PLS-DA)	Unscrambler ®	Classification of sample (Flood or Non-flooded)
IV	Linear regression (Ordinary Least Squares (OLS)) Probabilistic (Probit)	R / R-studio	Determine significant variables affecting Willingness to Pay (WTP) to avoid flooding (WTP vs. independent variables)

3.2 Empirical data

The basis for the empirical data in Paper I differed from the other papers. This study was based on a survey among technical staff combined with data from various national registers. The overall issue was related to improvement of the drainage and sewer system in a certain reference year. The three remaining papers had in common that they were all based on experiences from urban floods.

The samples in all studies were associated with corresponding variables, relevant for the study. All cases referred to Norwegian conditions, except the first paper, which also included Sweden and Denmark. As most countries, at least in Western Europe are similarly organized and are facing the same challenges from urban floods, the outcome is considered to be relevant outside Norway and Scandinavia.

3.2.1 Empirical data (Paper I)

Several factors, such as technical conditions, events, economy and competence etc., are believed to affect the priorities which are chosen when it comes to urban flood prevention. In this study, it was assumed that, as discussed in Sec. 2, there is an ongoing regime shift in stormwater management towards more sustainable solutions.

Representatives from the largest Scandinavian cities (25 cities in each of the countries, Norway, Sweden and Denmark) were invited to take part in a survey. The participants were asked questions about the measures of existing drainage and sewer system in a given reference year (2010). The key questions were triggering reasons and applied methods when improving the system. In addition, they were asked questions about the condition of the system, availability of staff, and financial constraints etc. From the survey in Norway, 22 of 25 cities (88%) responded. Similar numbers in Sweden were 14 of 25 (56%) and in Denmark 16 of 25 (64%). Due to incomplete answers, two respondents, one from Sweden and one from Denmark were rejected.

Additionally, quantitative data from national registers (Bedre VA (Norway), VASS (Sweden) and Danva benchmarking (Denmark)) for the reference year 2010 were extracted. Accordingly, weighting of the results by the economy or population of the cities, would have resulted in a bias towards the trends in the largest cities (weighted answers from the smallest cities would have counted a small percentage relative to the largest cities). Since the main purpose was to capture trends, the use of non-weighted averages for each country was chosen.

3.2.2 Dataset with the basis in Insurance claims (Papers II and III)

The empirical data in Papers II and III were based on access to a Norwegian national database of registered insurance claims administered by Finance Norway, which is the industry organization for the Norwegian finance and insurance companies. For Papers II and III, the sample assumed floods within a district due to rainfall for the period 2006-2012. Fredrikstad, the sixth largest city in Norway, was chosen as the case area in this study due to several flood incidents the past decade.

Besides the objects selected from insurance data, Paper III included a set of randomized addresses for comparison and in contrast to flooded addresses from the insurance register.

Insurance data (Papers II and III)

Insurance companies are frequently experiencing the economic impact of urban floods. A national reporting system was standardized in 2006, and the market share for the insurance companies using the system in Norway is approximately 90 %. All data concerning the damage are coded in three categories (Finance Norway, 2017a):

- Installation: A description of where the malfunction that has led to the damage is located e.g. water pipes, indoor, outdoor, sewer mains.
- Source: A description of the underlying reason for the damage, e.g. precipitation, water supply.
- Cause: Describes the actual cause for the damage, e.g. stop in sewers, aging, frost, malfunction.

This information was further used to select relevant claims for the study. Besides classification (Installation, Source and Cause), the following characteristics were found suitable for the studies:

- Date of damage (*Paper II*)
- Address where the damage occurred (*Paper III*)
- Compensation sum (*Papers II and III*)

Rainfall data linked to insurance claims (Paper II)

Precipitation data was collected from a network of rain gauges throughout the selected district, and they were all located within a radius of 10 km.

Rainfall data in Paper II addressed the insurance claims associated with rainfall for different time scales (seasonal, day-week and shorter than 24h). The sum of the costs of these claims were further used as a measurement for the overall damages for a certain date for the entire study area. Related to these dates, data from different rain gauges and time intervals were registered. Through a multivariate analysis and use of PCA, these variables were reduced to fewer latent variables, which were considered to characterize the rain event.

Geocoding, terrain and sewer data (Paper III)

Initially, in Paper III it was intended to determine flood relevant terrain and sewer data to the selected addresses. Geocoding is a very effective method for generating environmental variables describing the local morphology surrounding the sample buildings. This is the process of assigning coordinates to units in a table based on spatial information. By matching the addresses with official register (the national cadaster), the coordinates were found. Furthermore, by using text-matching algorithms in Python^{tm} (programming language), these units were geocoded.

Geographic information system (GIS) was used to generate terrain representations and from these, terrain variables were extracted. Terrain is commonly represented in GIS using the raster format where the entire study area is tessellated into quadratic cells. Terrain parameters were generated from digital elevation models (DEM) at three different resolutions (cell sizes): 1, 10 and 50 meters.

Terrain parameters assumed to be relevant to flooding consisted of 31 independent variables. They could further be divided in four categories:

- Distance (elevation z, distance to coast)
- Slope (the slope gradient)
- Area (permeable, impermeable and sum, surrounding or up-and downstream the house)
- Terrain Curvature (plan and profile)

Additionally, a comprehensive manual search was carried out on each address to determine the most likely point of connection to the sewer mains, including measuring the distances. Sewer data were associated with seven independent variables.

Finally, 38 independent terrain and sewer variables defined either as categorical or numerical were linked to the addresses. All objects were either derived from a former flooded (F) or random (R) selected address.

3.2.3 Dataset for measuring Insecurity to floods (Paper IV)

Dealing with non-market values– Contingent Valuation

Cost and benefits are defined in terms of individuals' preferences. Individuals get a benefit when he/she receives something in return and he/she is willing to give up something else that is valued. In a Cost- benefit analysis (CBA) -approach it is essential to measure all relevant costs and benefits in one single dimension, and as a 'matter of convention', money is the standard measurement.

According to Chatterton et al. (2010) insecurity and psychological stress was estimated to be the second most costly sub-item for the society in the aftermath of a fluvial flood in England in 2007. Only damages to houses and businesses were considered to have a higher cost to society.

While private goods can be valued using market prices, questionnaire studies are frequently used to value changes in the quality or quantity of environmental and other public goods like flood insecurity (Messner et al., 2007, Navrud and Magnussen, 2013). Contingent Valuation (CV) method was found suitable to value the welfare loss from flooding (Bateman, 2002), as the intention was to assess the value of the goods' safety for flood as a whole. While there have been CV surveys assessing insecurity from fluvial floods (Botzen et al., 2009, Grann, 2011, DEFRA, 2004), there is to our knowledge, no applications of the CV method to value insecurity from urban floods.

Measuring insecurity to floods

The main purpose of Paper IV was to apply the CV method to estimate households´ willingness-to-pay (WTP) for security to floods. This could either be seen as a measurement of avoided welfare loss or social benefits of achieving this security.

Following Grann (2011), households´ WTP for security to urban floods was estimated as the difference in WTP between two CV scenarios; A and B. Firstly, in scenario A, participants were asked what the highest sum that they were willing to pay was, in increased annual municipal fees, for the local authorities to implement measures that would fully prevent all urban floods (wtpA). Secondly, in scenario B, they were asked what the highest sum that they were willing to pay was for an additional home insurance that would cover all their future damages from urban flooding, including their current deductible (wtpB). Thus, in both scenarios, they would pay to have no personal costs from the flooding; i.e. in scenario A there would be no floods, and in scenario B they would get all their costs concerning damage on property and personal belongings covered.

However, in scenario B there would still be uncertainty related to whether flooding of their property would actually occur. Thus, the difference between wtpA and wtpB was, in this study, regarded as the households´ WTP to avoiding the insecurity of urban flooding (wtpAB = wtpA – wtpB).

This CV survey was carried out as an internet panel survey of a sample of 1060 respondents (each representing one household) in Norwegian cities, with different levels of exposure to urban floods. A representative sample of the overall Norwegian population was not intended. Rather, we were aiming for a set of objects of urban households being exposed to urban floods at different levels; from *not* to *very* exposed.

Our questionnaire consisted of the following five parts:

(1) Introductory part, which put urban floods in a broader context, and helped respondents distinguish between different levels of floods.
(2) Attitudinal and behavioral question.
(3) Two CV scenarios (A: 'Preventive measures' and B: 'Insurance') with accompanying WTP questions (wtpA and wtpB), which were used to reveal respondents´ WTP to avoid insecurity from urban floods.
(4) Follow-up questions about the reasons for paying or not paying.
(5) Questions about demographic (age, education etc.), personal and household income variables.

We excluded respondents with missing or unreliable responses to the WTP-questions. According to Bateman (2002), this covers the following three categories:

i. 'Don't know'- responses to the WTP-questions.
ii. 'Protest zero bids', i.e. respondents stating wtp=0, and selecting one alternative which revealed that they had not stated their 'true value' as the main reason for the zero response.
iii. Unrealistically high WTP bids; i.e. respondents who refused to take the survey seriously and/or provided unrealistically high bids. (Only one respondent was identified in this category.)

Additionally, there were numbers of respondents with inconsistent non-zero WTP bids; defined as wtpAB being negative; meaning wtpA< wtpB. An assumption was that scenario A should make households better off, or at least as well off as B. Negative values of wtpAB indicated that they either had answered incorrectly or did not believe in the scenarios. Hence, respondents with wtpAB<0 were then removed from further analysis. Finally, the net sample consisted of 643 respondents, out of which 311 and 332, respectively, diplayed positive and real zero WTP, to avoid insecurity from urban flooding.

3.2.4 Summarising empiri

The dataset in Papers I-IV finally consisted of different sources, numbers and variables and summarised in Table 2:

***Table 3:** Summarising empiri Paper I-IV*

Paper	Source of data	Net sample N	Dependent variable	Indep.. variable N	Independent variables
I	Municipality officials / national registers	50[1)]	-	-	-
II	Data of insurance claims + Rain data		Sum for case area - payouts per rain event		Rainfall data related to districts:
a)		1076			Seasonal rainfall (Month)
b)		32		12	Long-time rainfall (Day/week)
c)		125		5	Rainfall, duration 30-720 min
III	Data of insurance claims + Random data	179 168	Flooded and Random addresses	38	Terrain and Sewer data related to single houses
IV	Survey data from a questionnaire	643	Willingness to Pay	7-9	Socio economic, Flood experiences, Insecurity related to individual respondents

[1)] Number of cities included from the questionnaire-study

4 Results and discussion

4.1 Addressing Flooding and SuDS when Improving Drainage and Sewerage Systems – A Comparative Study of Selected Scandinavian Cities - (Paper I)

The purpose of this study was to investigate how floods and SUDS are being handled and how improvements of drainage and sewer systems are planned and carried out. In addition, the study included an investigation of how measures related to stormwater issues in general were undertaken. It was restricted to Scandinavian countries, as they are facing roughly the same challenges when it comes to climate change. Moreover, the water and sewer sectors are similarly organized, in the sense that each municipality has the ownership of the main drainage and sewer system. Therefore, the conditions in the largest cities in Norway, Sweden and Denmark were examined.

This study was not aiming for exact results, and should rather be perceived as an exploratory study to capture trends. The study provides a background and motivation for the following studies. The results of this study, across countries, are listed below:

- Every year there is a considerable number of urban floods in all Scandinavian countries.
- The drainage and sewer systems in the largest cities in Norway were generally in poorer

technical condition compared to those of Sweden and Denmark. Norway had a lower rate of combined sewer systems than Denmark, but seemed to have more leakage into the drainage systems.

- Flooding was ranked as the most common cause for improvement of the sewer system in Sweden and Denmark. In Norway pollution was ranked the highest.
- There was little variation in the methods for improving the sewer systems. The most frequently used method involved the excavation and replacement of old combined sewers with new separate ones.
- The differences in the use of methods between Norway on the one hand and Sweden and Denmark on the other, could not be explained by the countries meeting different challenges according to climate changes.
- Investments in SUDS were not common in Norway.
- When it came to implementing new methods, it seemed that Norway, and to some degree Sweden, were less efficacious than Denmark, despite the fact that Norwegian municipalities had better frameworks for financing improvements.

Limitations /validation of the study

- A higher number of respondents would probably made the results more significant. Anyway, as long as the aim of the study was to capture trends, the number of respondents and the method used, were considered sufficient.
- The limitations inherent in the survey method, for example related fixed response items, should be taken into consideration. This may have been mitigated by a comprehensive qualitative interview study, which would have given the opportunity to clarify any ambiguous questions.
- Although the dataset in Table 1 in Paper I was intended to cover the same phenomena, there might be differences, since a statistical register in one country can be slightly different from another.
- 'Standard' technical terms were applied as far as possible, but there can be some nuances in how concepts are perceived. In retrospect, a stricter definition related to the term SUDS should have been added to the survey. The same applies to the distinction between drainage and sewer system. Anyway, there is no indication of confusion regarding this.
- The median number of inhabitants in the Norwegian cities that responded was approximately 47,300, half of the corresponding numbers in Sweden and Denmark. However, there were no significant tendencies suggesting that the larger cities used other methods and had different reasons to improve the systems than the smaller.
- In Table 1 in Paper I, a comparison of factors that may affect flooding and SUDS-focus in Scandinavian countries are outlined. Empirical data has been obtained from multiple sources and several independent statistical sources and constitute a data triangulation. According to Yin (2009) multiple sources of evidence can provide measures of the same phenomenon, and will strengthen the validity of the study. An example of this is that

various statistical sources indicate that the technical condition of the drainage and sewer systems in Norway is worse, compared to the other countries. Finally, there seemed to be an interrelation between the lack of quantitative regulations in Norway and little use of innovative tools towards a more sustainable stormwater management. Additionally, several key findings from Norway in this study were in accordance with the results from a more recent survey from a Norwegian report regarding the urban stormwater issue (Government N, 2015). Among others things, that study revealed that even where there was awareness of the urban flood; competence was regarded as a limiting factor. The study also confirmed that there was a need for more regulations and guidelines due to measures in already built-up area.

Outcome/conclusions

- Extensive use of traditional methods for improvement indicated that indicated that decision-making in Norway is largely based on engineering standard methods. However, the implementation of interdisciplinary processes was not evaluated in this study.
- Sector laws seemed to give the wastewater management increased attention in Sweden and Denmark, while such law has not yet been introduced in Norway. However, the fact that these laws were passed quite recently suggests that this was probably not the main explanation why Norway had different priorities.
- There was an indication that current and past regulations in Norway did not motivate the use of innovative solutions such as SUDS.
- Moreover, the lack of regulations in Norway might explain why comparable measurements of the present conditions are unavailable. The need for improvements might have been defined by other criteria e.g. rate of network renewal. This may further have led to the general perception that the methods in themselves, rather than actual solutions, are a goal in itself.
- Stricter regulations and clear goals with respect to urban floods seemed to be missing in Norway.
- In light of the perspectives emphasized in sec. 2.1, Paper I indicated that there is a higher level of preparedness regarding the increased challenge of urban flood management in Sweden and Denmark compared to Norway. This was mainly justified by the fact that respondents in Sweden and Denmark ranked flooding as a more important cause for improvement of the drainage and sewer system than pollution. Furthermore, Norwegian respondents reported less capacity of the system and simultaneously less use of SUDS. The relatively one-sided use of conventional and less flexible methods for improvement in Norway, indicated a stormwater regime which in practice still is strongly associated with traditional engineered-based principles.

4.2 Correlation between extreme rainfall and insurance claims due to urban flooding – case study Fredrikstad, Norway (Paper II)

In this paper the focus was on relation between rainfall characteristics and registered insurance claims. Principal Component Analysis (PCA) was applied, as this reduces a large number of variables to fewer latent variables to examine correlation among features.

Certain rain events were selected and characterized with recorded rainfall for three different time resolutions:

- Events and Monthly rainfall
- Events and Daily / Weekly rainfall
- Events and Short-period rainfall

Events and Monthly rainfall

When it came to seasonal rain in Fredrikstad 2006-2012, it was clear that the extents of claims followed by urban flooding was strongly associated with the late summer rainfall. Figure 3 in Paper II had a distinct peak, and 79% of the payouts from flooding in Fredrikstad during this time period, occurred in July, August and September.

This initial analysis showed that when it comes to flooding, there was only a risk of major damages during some months of the year.

However, the provision of information about, and increased levels of awareness of, which time periods that have a general higher risk of urban floods, can contribute to reducing such damages. One simple way for professionals to implement this in practice, can be to clear watercourses prior to the periods known to have a higher risk.

Events and Daily / Weekly rainfall

In this analysis, variables associated with recorded rainfall at four different rain gauges on dates with heavy rain were added together with rainfall the preceding day and week (12 variables). The sample consisted of certain dates (N=32). A PCA was conducted to reduce the dimensionality of the dataset and thus made the dataset more interpretable.

Possibly the most important finding from this analysis was that dates with no claims (denoted '*no*') in the score plot are located to the left along the PC-1 axis (See Figure 4b in Paper II). Simultaneously, variables indicating high amount of rain the present day were located at the right side of PC-1 axis in the loading plot (See Figure 4a in Paper II). This means that little rain the preceding days of an event, tends to reduce the risk of extensive floods. Saturated ground and/or already filled drainage courses seemed to have a great impact on the extent of floods. Finally, this analysis indicated that when heavy rain is forecasted, the level of emergency preparedness should be higher if extensive rain has fallen in the days in advance.

It is reasonable to assume that the runoff coefficient in rural areas is highly affected by the saturation of the ground, as the infiltration capacity changes with saturation. Thus, an interesting aspect, which should be paid attention to, is how the runoff coefficient fluctuates in urban areas due to level of saturation. Further research should examine to what degree differences in runoff coefficient from ‘ordinary’ to extreme conditions affect design criteria of urban drainage systems.

Events and Short-period rainfall

In the final analysis, another PCA was made upon a dataset consisting of certain rain events and corresponding recordings of short-time rainfall. Unlike the study above, the sample consisted of rainfall recorded by unique rain gauges (N=125). The variables analysed were maximum rainfall intensity within certain time-span (30-60-120-360-720 min), the current day (5 variables). Since the rainfall associated with the first variable, mostly was included in the second etc., the dataset was intercorrelated. Thus, PC-1 not surprisingly captured most of the variance in the dataset. In the study, the two first principal components described almost all variance in the dataset (99%). The variables for the shortest duration rainfall (30 and 60 min) were slightly below the PC-1 axis (negative PC-2 value) (according to Figure 6 in Paper II), while the remaining variables were located above this axis.

Generally, an Intensity-Duration-Frequency curve (IDF-curve) shows the probability for a certain rainfall intensity in a specific region. The calculated probability is based on statistical analysis of recorded rainfall data for a long period, typically 30 years. This IDF-curve is essential when designing drainage systems for a certain location.

The more intensive rainfall, the further to the right side of the score plot the measures will be found. As expected, the plots furthermost to the right resulted in higher compensation sums for flood damages. Furthermore, several objects in the score plot marked as ‘*exp*’ (expensive) were above the PC-1-axis in the 1st quadrant. This indicates that the most costly events in this study were associated with extreme rainfall with duration >120 min, relative to the IDF-values.

Another finding of interest was that relatively few rain events were located in the 4th quadrant of the score plot, seen in Figure 6 in Paper II. This indicates that there were few, short-duration rain incidents (<120 min), measured during the period of observation. In terms of spatial and temporal distribution, short-duration convective rain, are considered harder to forecast than more extensive rainfalls. Statistically, these rainfalls are the most intensive, and provide the largest flow in the drainage system.

Limitation/Validation of the study in Paper II

- Even though results from this study make sense, they were restricted to this case area and a limited time period. Although there were extensive recordings of rainfall, data were missing for some events. More samples added to the dataset, in terms of insurance data and events, would have made the conclusions more significant. It is therefore recommended that additional analyses are carried out, using other methods and more data, before action is taken to implement measures.
- Indeed, there were some major events during these years e.g. 14 August 2008, which had a great impact on the results from seasonal recordings. However, despite the elimination of this particular, the dataset would still have peaked in the late summer months.

Furthermore, the heavy, late summer rain in this part of Norway is a well-known phenomenon (Fredrikstad municipality, 2007).

- In Figure 4 in Paper II, it is assumed that the results from the rain gauges distributed in the case area altogether characterize the conditions the date of the particular event and day/week before. This is a crude simplification, as costly events can occur from rainfall recorded at only parts of the area studied. Nevertheless, the correlation between the rain gauges for the events were well described, confirmed by the fact that they were relatively highly clustered in the PCA-plot.
- For short-time measurements (see Figure 6 in Paper II), all objects (scores) are related to certain rain gauges, but labelled in accordance with the sum of damages in the entire case area. As mentioned above, this is also a simplification, as short-duration rainfall often has limited spatial distribution and sometimes only occurs in parts of an area. However, these objects could be detected in the score plot by the red-market objects located to the left side of the origin. This can probably be interpreted as the expensive flood event that date was a result of rain not hitting this particular rain gauge.

Overall findings in Paper II study

The results from this particular study indicated a correlation between certain rainfall characteristics and water-related insurance claims, which it is possible to warn against and prepare for.

Features of rain characteristics from this study:

- Late summer-time rainfall causes more costly damages.
- The amount of rain days/week prior to the rain event has an impact on the extent of damages.
- Short-term heavy rain, > 120 min causes more damages than even shorter and more intensive rain.

Information of these features to the public can contribute to risk reduction of urban floods as it:

- raises awareness of preparedness to rain events vs. the extent of damages
- emphasizes that well-timed and flexible measures are beneficial in terms of reduced flood risk for the society

4.3 Evaluating Flood Exposure for Properties in Urban Areas Using a Multivariate Modelling Technique (Paper III)

In this study, terrain and sewer parameters associated with flooded and non-flooded addresses, were investigated. All addresses were associated with the Building Central Point (BCP) obtained from the Norwegian cadaster. The aim was to reveal patterns and correlations between characteristics of location of a house and the impact of flooding. From the dataset it was built a model to determine whether a house, based on the terrain and sewer data of that particular address, could be identified as flooded or not, without having knowledge of previous flood events. As the latter was formulated as a classification issue with two response variables (flooded/non flooded), Partial Least Squares – Discriminant Analysis (PLS-DA) was found suitable for this study

Two classes, flooded (F) and random (R), were defined. Full name and a brief description of each variable, as well as average and Standard Deviation-values (SD), are shown in Table 1 in Paper III.

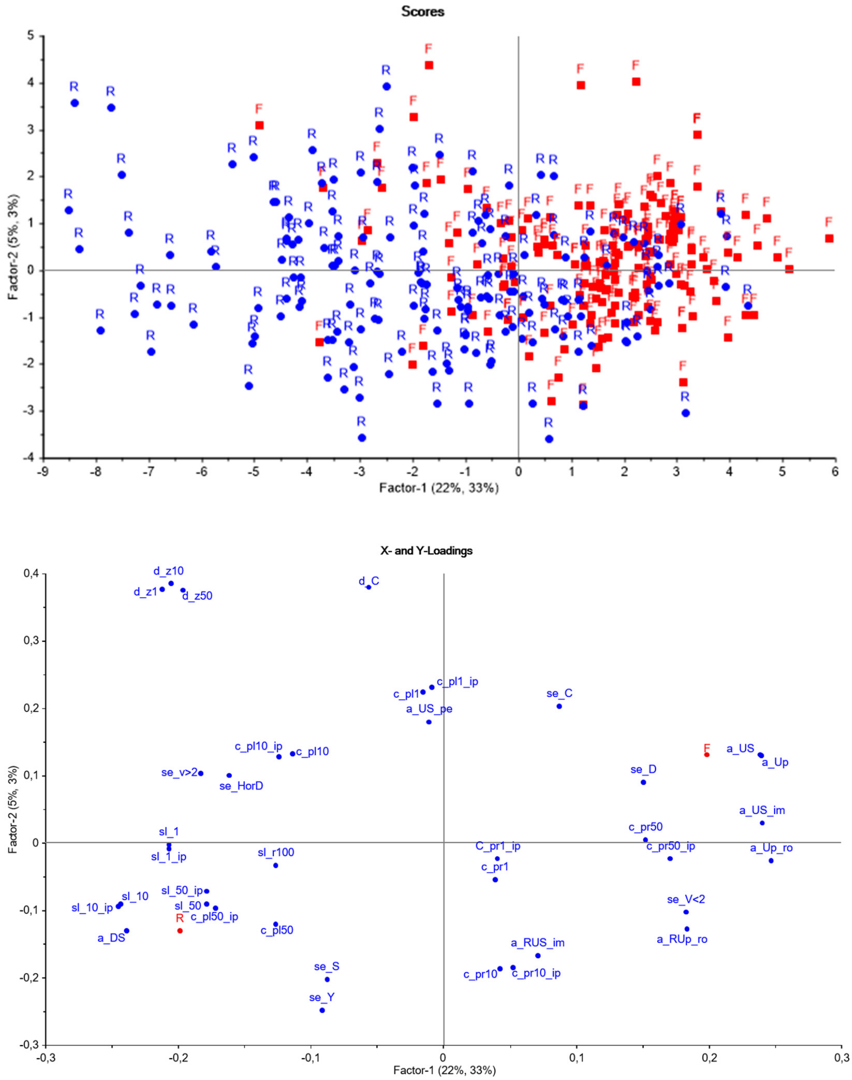

Figure 6: *Scores (upper) and loading (lower) plot computed from PLS-DA*

The output from the PLS-DA model in terms of score and loading plot is shown in Figure 6.

From the model, the first two factors (latent variables) in sum described 27% and 36% of the variance in the dataset, for X and Y respectively.

From the score plot, we see the red-marked dots (F) are mostly located to the right (positive value of Factor-1), while most of the random data is to the left. The separation between the red and blue dots indicates the different structure of the two classes. This difference is mainly explained by Factor-1. It is hard to discriminate the classes along the Factor-2 axis (or any other factors at higher level). The loading plot in Figure 6 shows the importance of each variable for Factors 1 and 2, respectively.

The flooded addresses (F) are rightmost in the score plot. Simultaneously, impervious and upstream area surrounding BCP (variables starting with '*a_U*' in the loading plot in Figure 6, see Table 1 in Paper III for further details) are to the right in the loading plot. This indicates that these variables are significant for flood-prone properties.

Variables describing distance to the sea (*d_C*) seemed to have relatively little influence, as it in the loading plot was located close to the centre of Factor-1. Elevation (*d_z*) turned out to have more impact as this variable is plotted to the left along the Factor-1 axis and inversely correlated with flood-prone homes. Terrain curvature determines whether a given part of a surface is convex or concave. For plan curvature and profile curvature, the sign rules are inversely defined. A negative and a positive number respectively describe concavity. Profile curvature indicates the shape of the surface in the steepest direction, and if the terrain flattens into a concave curvature, the flow will currently slow down and the water level will rise. In this study, flooded addresses (F) can be associated with a concave profile curvature (variables starting with '*c-pr*') as they are located to the right side in both plots in Figure 6.

Unlike urban floods, another flood-type, flash flood, occurs when heavy rain is falling on the slopes. The water will immediately drain to rivers that hold little or no water. This can be potentially dangerous, since it causes a sudden rise in the water level of the river that is difficult to forecast. In 2003, a so-called Flash Flood Potential Index (FFPI) was presented. Originally, this index was based on the parameters slope, land use, soil type and vegetation cover. Slope was given a slightly higher weight than the other parameters that were weighted equally. (Smith, 2003). Later the model has been developed and high slope as well as urban areas have been emphasized (Zogg and Deitsch, 2013). A comparison between the FFPI and the study reported here, illustrates differences between the two flood types. As steep slopes are characteristic of areas with high FFPI, this study showed that little slope give increased potential for flood related damages in urban areas. A possible outcome of this study can be development of an index that characterizes an address' potential exposure to urban floods, based on the most significant variables. Furthermore, this can be put into a GIS-tool along with other flood characteristics for production of a comprehensive risk map.

Limitation/Validation of this study

- This work showed that PLS-DA is a suitable tool to predict the flood-prone nature of a property area. However, as can be seen from Figure 6, only 36% of the variance in the responses was captured by the two first factors of the model. This can be regarded as an applicable value for a 'non-laboratory investigation', even if much of the variance is not captured by the model.

- Even though the results from this study seemed reasonable and justified by hydraulic principles, they are restricted to this case area and for a particular time period. A larger dataset and data from other cities would have strengthened the conclusions. Manual methods used to extract sewer data can be a source of error. Automatic methods should be developed to reduce the possibility of human error. Despite this, there were no indications of incorrect data due to manual methods.
- A simplification was made for calculation of the size of the upstream area, as all cells above the BCP level were included. However, an area of higher elevation than BCP within a given zone, does not necessarily mean that water is drained through BCP. Still, the same procedure was used for all addresses, and there were no indications that this simplification led to bias in the model.
- When extracting terrain variables, the locations of BCP may be anywhere within the cell, not necessarily in the centre of the house. To overcome this problem, some terrain variables were derived from the weighted mean of the four nearest pixel values. The variables taking nearest cells into account are referred to as interpolated values and end with '*ip*' in the loading plot in Figure 6. As can be seen from this plot, these interpolated values are close to variables based on values from one single cell.
- As mentioned in Paper III, this study had a link to the sewer system. Thus, ca 15% of the addresses were excluded from the sample as the damage could not likely be associated with the sewer system.
- The PLS-DA model was validated by cross validation. Using the validated predicted values for classification by applying the 'winner-takes-all-strategy' as described in Paper III, 84% of the initially flooded houses were correctly classified.

Outcome from this study

The overall results from this study revealed some distinctive characteristics for the most exposed properties in the case area in Fredrikstad during 2006-2012:

- Houses in flat areas or concave curvature are more exposed.
- Houses on plots with a large upstream area are more exposed.
- Houses in steep slopes are less exposed.

In a broader perspective, this model can:

- be a useful tool when planning new sites
- quantify and rank an address' exposure to floods based on objective criteria
- make people aware of the risk of floods

4.4 Singing in the rain: Valuing the economic benefits of avoiding insecurity from urban flooding (Paper IV)

This study was based on a survey, and the purpose was to-fold: First, identifying significant variables influencing people's willingness to pay (WTP) for reduction of insecurity, secondly, to estimate peoples actual WTP. The most appropriate tool for econometric analysis was found to be Ordinary Least Squares (OLS) and Probit models, calculating the WTP on different combinations of the explanatory variables. The results were presented as an econometric analysis by calculating the mean WTP.

In the following, WTP for scenario A (preventive measures) and scenario B (insurance), were denoted wtpA and wtpB, respectively. WTP to avoid the insecurity for urban flooding (i.e. wtpA - wtpB) was denoted wtpAB.

Econometric analysis

Tables 4, 5 and 6 in Paper IV in sum presented 13 models regressing the WTP to avoid insecurity. Table 4 showed Probit models, aiming to investigate significant variables with binary responses, i.e. people who wanted to pay something vs. nothing for security to floods (wtpAB>0 vs. wtpAB=0). In Table 5, OLS models were made, trying to explore variables that have an impact on the magnitude of wtpAB. Finally, Table 6 (Models 11-13) could be seen as a more detailed version the previous table, including the most significant variables split into further sub-categories.

Four of the variables in the tables, characterizing physical and mental 'closeness' to urban floods turned out to be particularly interesting. These variables indicated the respondents' feeling of exposure or annoyance related to possible urban floods at home. Furthermore, if they had experienced flooding of their own house or had knowledge of any flooded houses in the region. Variables covering 'closeness' were associated with Exposed, Annoyed, DistantFlood and OwnExperience.

In Table 4 in Paper IV, Age is significant and negative, showing that there is a lower probability of being willing to pay something with higher age. But among those that are willing to pay something, and according to Models 7 and 8 in Table 5, the WTP seems to increase with higher age. Models 2-5 in Table 4 implied that men rather than women stated wtpAB= 0. Furthermore, in Models 2-4 the 'closeness'-variables turned out to be significant with a positive sign, indicating that experiences with floods have an impact on whether you want to pay something to avoid insecurity.

In Table 5 in Paper IV, all models showed that the 'closeness' variables were significant (at the 5% level) and positive, confirming the expectations that people feeling close to flooding have higher WTP than others. In the survey, all these variables, except OwnExperience, had several options. In order to see whether each reply options/categories were significant, we re-ran Models 7-9, but now with each category separated in three dummy values. To achieve this a 'hidden' category was chosen, and for each model it was the one, 'farthest' away from floods from floods. These categories were: *'Not exposed at all', 'Not annoyed at all'* and *'No – I don't know any others within my region affected by floods'*.

Even though Age was significant at the 10% level in Models 11-12 in Table 6 in Paper IV, none of the demographic variables seemed to affect WTP as much as Exposed, Annoyed and DistantFlood.

Calculating mean WTP

Based on the net sample of 643 respondents, the mean WTP was calculated to avoid insecurity from urban flooding (i.e. for all respondents with wtpAB ≥ 0). Mean WTP is the correct welfare measure in Cost-Benefit Analysis (CBA) of the preventive measures, and can be aggregated over the number of affected households for each project in order to estimate the aggregated benefits from avoided insecurity.

The sample was not representative of the overall population, because 20% of respondents stated that they were prone to flooding, while in general probably less than 5 % are affected. Thus, conducting a CBA of preventive measures nationwide, using the mean WTP estimate from our survey, would have been incorrect. Instead, Table 7 in Paper IV presents estimates of mean WTP for each category of the 'closeness'-variables. Restricted to single projects, it should be possible to multiply these estimates with the corresponding number of affected households in each category. Our sample was not representative of the Norwegian population with regard to Income and Education, as both were considerably higher in our sample than in the Norwegian population (SSB, 2016a, SSB, 2016b). However, as opposed to the 'closeness' variables, none of these had significant impact on WTP. Thus, there was no reason to make adjustments for the demographic variables.

When we compared the highest level/subcategory of the three main variables, we found that the lowest WTP estimate belonged to respondents who had personally experienced flood. This indicates more insecurity among those who believe they can be affected than those who actually had been (OwnExperience). An explanation for this finding may be that people who have experienced flood may have found it to be less stressful than they had expected, and/or that these people, subsequent to the flooding, have put in place preventive measures (e.g. moving all valuables in the basement to a higher floor). This can have made them less worry regarding damages from new urban floods.

For people not exposed or affected, the mean WTP /Household/year was quite stable around NOK 400[2].

Figures 7 and 8 are derived from Table 7 in Paper IV. They display the WTP separated in the subcategories of exposure and distance to former floods, respectively. In both tables, we clearly see how Willingness to Pay increases with respect to how exposed they feel and how close they have lived to other former flooded houses.

[2] NOK 1 = €0.11 (2015

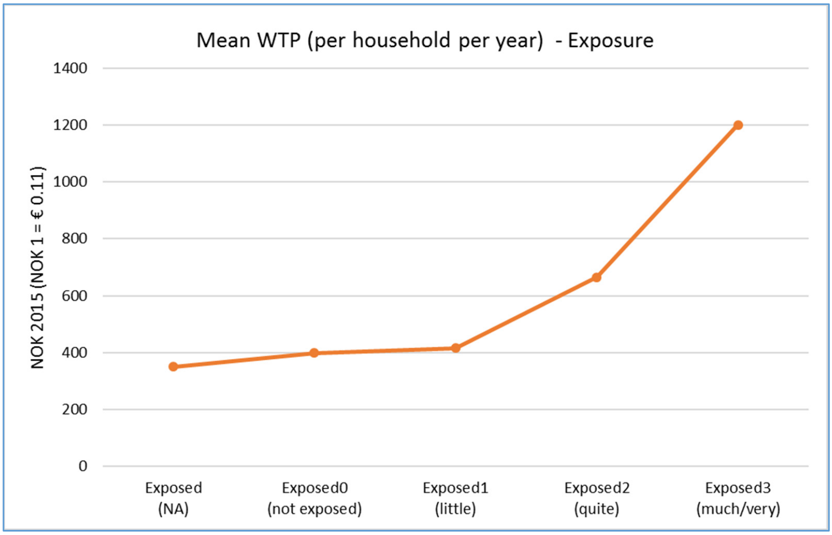

Figure 7: *Mean Willingness to Pay (WTP) as a function of exposure to floods*

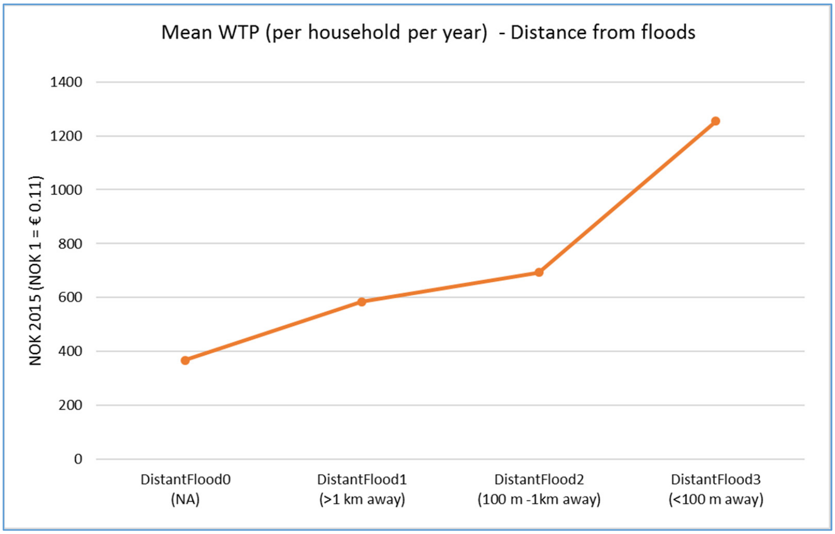

Figure 8: *Mean Willingness to Pay (WTP) as a function of Distance to former floods*

For practical purposes, the WTP estimates from the variable based on distance to other floods (DistantFlood), are regarded as the most appropriate for smaller projects. If public preventive flood projects should be initiated, usually more than one household should be affected. Based on the results from the survey and conservative estimates, we calculate the insecurity cost within the 1 km zone from the previously affected areas to be NOK 800-900 per household per year. Outside this zone, we estimate WTP to be NOK 400 per household per year.

When these results are compared with two other studies, valuing impacts from fluvial (river floods), rather than pluvial (heavy rain), differences were found. DEFRA (2004) recommended a value of 200 2004-UK£ per household per year for affected households (about NOK 2900 in 2015). Further, Grann (2011) conducted a CV study near Drammen, Norway 2011 and found an annual WTP/household/year to avoid insecurity from river flooding to be about NOK 100 (in 2015). The first study was conducted just after a disastrous flood, while in the second no recent floods had occurred. This is probably one explanation for the different values across the studies.

Limitation/Validation of the study

- In the Contingent Valuation-studies (CV), respondents were asked about their preferences for a constructed and hypothetical market. In general, the hypothetical market is the main argument against CV. Some critics argue that the respondents are able to place this in a real context knowing this is hypothetical. Anyway, today CV is seen as relatively uncontroversial, though it should be considered as an estimate. (Navrud, 2005, Boardman, 2011, Messner et al., 2007).
- The fact that 39% of the respondents had to be excluded from the gross sample due to inconsistencies in their WTP answers, indicates some challenges for the respondents, even though only 14% of the respondents reported this to be a difficult survey. Furthermore, for households most exposed to urban floods, there were relatively few observations, making WTP estimates for this group more uncertain than for the other levels of exposure/closeness.
- According to economic theory, WTP should increase with income. Most CV studies find a significant, positive effect of income on WTP, and usually the income elasticity of WTP is less than 1 (Kristrom and Riera, 1996, Bateman, 2002). This means that an 1% increase in income leads to a less than 1 % increase in WTP. However, in this study, wtpAB was not significant (at the 10 % level), neither with income as the single variable nor with Age, Male, HighEducation, Worker, Basement. In OLS models of wtpA and wtpB (only positive values, as for wtpAB), a significant and positive income elasticity of WTP was found when regressing only wtpB and personal income (PersInc) (0.49). Personal income was still significant and positive (0.47) when more socio-economic variables were added to the model. For the other models, income elasticity was not significantly different from zero. Anyway, the findings of the income elasticity in this study were in accordance with a similar CV study from fluvial floods (Grann, 2011).

Outcome from Paper IV- study

- Personal experiences with urban floods is in general more significant than socio-economic factors such as age, gender, income etc. when it comes to stating the insecurity cost.
- The 'closer' to floods, the more significant the Willingness To Pay-value is.
- The insecurity cost for non-affected is on average NOK 400, as opposed to people who are affected and who, on average are willing to pay 2-3 times more for security.
- In a broader context, this model can create awareness of insecurity as a 'continuous cost' for affected households. This study shows that insecurity lasts longer than the immediate flood event.

- In a broader perspective, this model can shed light on insecurity as a hidden, everyday psychological challenge.

This study was related to the emotional aspects of the impacts of urban floods that rarely become known. This focus might have the potential to trigger engagement and debate with an underlying clear objective; reducing the risk to whom it matters most. To adopt the method in practice and for decision-making, when prioritizing preventive measures against floods, it should be included in a Cost Benefit Analysis (CBA) together with other relevant, and probably more tangible data e.g. costs of former flood damages.

4.5 Summarising findings of this research

The four studies reported in the papers had separate research questions described in Table 1 in Section 1.3. The findings for each of the studies are summarised in Table 4 and 5 below:

Table 4: *Overview research questions and findings Paper I and II*

Paper	Research question	Findings
I	How is flood prevention and SUDS focused when Norwegian cities improve their drainage and sewer systems? Are there any differences amongst the Scandinavian countries in how the cities or the national authorities meet this issue?	Based on answers to survey and data from national registers, flood prevention measures in Norway were ranked as a less important target than reduced pollution. In the other Scandinavian countries, the opposite situation seemed to be true. At the time of the investigation, Denmark had recently had more extreme events than Sweden and Norway, but the survey did not provide a basis to link this to the high SUDS-focus. Comparison of legislation since the early 1990s indicated fewer requirements in Norway compared to other countries in terms loss of wastewater from the transportation system. Lower requirements might also have led to unclear goals, which can explain the use of traditional solutions. It was emphasized that stricter requirements could bring the issue of improvement more into focus, rather than the activity itself. This can further create new ideas and put more sustainable stormwater solutions into practice.
II	Are there characteristic fluctuations in short and long term rainfall, which affect insurance claims due to flooding?	The results indicated a correlation between rainfall and the extent of urban flooding. In the case area during the period 2006-2012, some flood events characteristics were registered, which it had been possible to forecast and prepare for. Municipalities might systematically take the seasonal fluctuations into account when developing their management plans, e.g. ensure cleaned waterways before the late summer rainfall is expected. Dry weather or little rain prior to an extreme rainfall event, generally led to less flood damages. Thus, the change in the runoff factor due to soil wetness seemed to have an impact on floods the case area. This case study showed that heavy rain lasting for >2h induced most claims. When heavy rain lasts for several hours, a large amount of water is accumulated. In such cases, efficient systems that drains the water away may be more appropriate than temporary storage of stormwater.

Table 5: *Overview research questions and findings Papers III and IV*

Paper	Research question	Findings
III	When it comes to location, are there any characteristics for houses affected by floods compared to non-flooded?	The study showed that sealed and large upstream areas, small slope and location in concave curvature, characterize addresses affected by urban floods. This can be regarded as features of residents highly exposed to urban floods. Locations in steep terrain contribute in the opposite direction. This study suggests developing an index as a possible way to describe exposure to floods. This might make individuals' aware of the risk and motivate them to conduct preventive measures.
IV	Are there any variables significantly affecting the willingness to pay to avoid urban floods? Is it possible to estimate insecurity of flooding in monetary terms and to specify an insecurity cost?	The study showed that variables related to 'closeness' to the floods, e.g. the feeling of being more exposed, own experiences and knowledge of others who are flood-affected, are significant variables for the insecurity cost. Socio-economic variables seemed to have little impact, except Age which indicated that younger people consider this a minor problem. The study showed that it was possible to estimate an insecurity-cost. For practical use, it was suggested that if there has been events within 1 km of a person's place of living, the willingness to pay per household amounted to NOK 800-900 per year. Outside this zone is about NOK 400 per household per year.

5 Summing up and overall conclusions

The current perspectives in urban flood management were discussed in section 2. Sustainable planning and an interdisciplinary approach were both considered to be key factors for managing the increasing urban stormwater challenge. Furthermore, a shifted approach from 'defence' to 'living with floods' also makes room for a more qualitative approach, e.g. illustrated by the risk triangle. In this final section similarities and differences across the papers are summed up, aiming to suggest ways of implementing relevant features of a future-oriented urban stormwater regime.

5.1 Interrelationship to the SUDS-concept

In Sec. 2.1 the SUDS-concept was introduced. It was contrasted to piped solutions as SUDS aims to dispose and transport stormwater on the surface. Indeed, they all refer to physical and structural measures. Generally, preventive flood measures can be divided into Structural and Non-structural, where the latter intends to keep people safe from flooding through emergency preparedness, warning systems, sustainable development or well-planned urban areas. According to Jha et al. (2012) all these measures are complementary and can be developed simultaneously. Despite the fact that non-structural measures do not cover physical constructions, it is reasonable to perceive them in line with the SUDS-concept. In this work, non-structural measures were regarded as a future-oriented way to meet the stormwater challenge. Characteristically, they are flexible and intend to optimize the drainage system in a sustainable way. For a city, optimal measures rarely consist of one single method, but a selection of appropriate solutions adapted for local conditions and requirements.

This work has not emphasized particular measures within the SUDS category. However, solutions for the challenges introduced in Papers II, III and IV, were all based on a sustainable mind-set, and on structural SUDS, as well as non-structural measures. All papers highlighted the importance of having knowledge of causes and occurrence of urban flooding. They also concluded by recommending sustainable and low-cost measures. Other commonalities were the flexible and holistic approach across the studies.

In general, the first study explored the state of the art of how SUDS are applied in Scandinavian countries. The three remaining papers can be linked to the SUDS-concept as listed below:

The **Paper II** study intended to emphasize:

- keeping floodwaters on the surface and to a large extent using temporary solutions.
- systematic, targeted and timed maintenance aiming to keep waterways clean and fully functional. This is regarded as a sustainable approach as it aims to optimize functionality of the existing system.
- emergency plans (for exposed and vulnerable areas) including information and warning to citizens. These measures are all regarded as low-cost as well as flexible to implement purchasing and maintenance of emergency equipment for flexible utilization.

The **Paper III** study focused on:

- developing multivariate models, mainly based on surface data.
- development of a potential urban flood index. This index can contribute to well-planned residential areas, considering significant exposure variables to reduce the potential for floods.
- implementation of an urban flood index that can make more people aware of their own flood risk. Furthermore, this can contribute to more innovative, low-cost solutions.
- a potential link between residents' flood risk and insurance premiums. This can also potentially encourage house owners in affected areas to install small scale preventive measures.

In **Paper IV,** the study:

- covered insecurity to urban floods, which can be considered as a missing link, or at least neglected part, in a complete CBA in order to prioritize preventive measures. Thus, the outcome can lead to more sustainable solutions by simultaneously having a focus on material damages as well as the 'intangible' impacts of urban floods
- can lead to more frequent use of CBA. This can open up for a broader discussion and a clearer distinction of costs and benefits when it comes to flood preventive measures. Furthermore, this can highlight a wider range of small scale, low cost measures with large

benefits that can be informative and emphasize simpler measures for residents living at higher elevated sites. Today most people are unaware that the way they dispose their drainage water indirectly can reduce the quality of life for those living downstream.

5.2 The interdisciplinary approach in the studies

As mentioned, another objective for this work was to highlight the need for an interdisciplinary approach to the urban flood issue. In section 2.2, it was argued that collaborating across disciplines can be beneficial when dealing with this. An important underlying perspective across all studies, was that all stakeholders, including 'ordinary' residents, could contribute to reduce the impact from urban floods. This was reinforced by the fact that all analyses had their basis in real experiences from people in the worst-off positions.

Fraser et al. (2006) highlight the need for indicators as a pathway to empowerment when it comes to sustainable development at community level. Furthermore, they recommended tools that bring professionals and citizens together and force a so-called bottom-up process, contrasted to top-down which is often associated with plans written by experts. In particular, the studies reported in Papers III and IV emphasize how individuals can be affected by floods. This might be a pathway to a broader involvement, not only for those with their own experiences, but also for non-affected individuals as they possibly become aware of and have compassion with the victims. The utilization of tools from this work can complement traditional and often engineer-based approaches to urban flood management. An additional outcome might be the implementation of innovative, low-cost measures as stakeholders become aware of urban floods as a collective challenge.

The studies reported in Papers II, III and IV may be perceived as an outcome of an interdisciplinary collaboration. Co-authors represented different professional skills, and empirical data applied in this work can be seen as 'outside' the traditional hydraulic and design approach. The professions and competences which can be considered as relevant for the issues undertaken, are listed below:

Paper II

- Insurers - damage data and risk analysis
- Meteorologists - measurements and forecasts of rainfall data
- Urban planners – suitable areas for location of houses and flood paths
- Geomaticians – mapping flood risk areas, applying GIS-tools
- Civil defence force/emergency services – emergency plans and preparedness to extreme events
- Residents/Citizens - input based on own experiences and awareness of the hazard
- Engineers / Municipal professionals responsible for clearing watercourses, coordinating the work in accordance with the general operation of the drainage and sewer system and to implement plans in practice

Paper III

- Insurers – damage data and risk management
- Geomaticians - creating GIS-variables and mapping flood risk areas by using GIS-tools

- Residents/Citizens –make general inputs based on their experiences
- Urban Planners/Real Estate developers – optimal localization of houses and settlements with respect to floods
- Engineers/Municipal professionals - responsible for seeing this issue in a broader perspective, to coordinate the work and to implement plans in practice

Paper IV

- Socio-economists – measuring welfare loss in monetary terms and using this in a CBA-analysis
- Citizens/respondents–general inputs based on own experiences
- Engineers/Municipal professionals–coordinating the work and implementing plans in practice by taking the insecurity into account when improving the drainage and sewer mains

5.3 Placing the studies into the risk-based framework

In section 2.3, the risk triangle was introduced as a framework linked to this study. Simultaneously, the risk of urban floods was defined as a function of Hazard, Exposure and Vulnerability.

The fact that this framework consists of three distinct concepts and contents, confirms the complexity and diversity associated with urban flood risk management. This framework underlines at least three important perspectives regarding this issue: Firstly, one needs to take a holistic view, which requires interdisciplinary collaboration. Secondly, determining urban flood risk is not exact mathematical science. Thus, a qualitative approach, rather than a quantitative, can be appropriate, as we have to deal with great uncertainties and have to implement different fields and scientific language. Finally, the triangle illustrates that even small scale measures can be developed independently and contribute positively to risk reduction.

It is possible to link the concepts of Hazard, Exposure and Vulnerability to the outcome of the studies reported in Papers II, III and IV.

When considering the outcome of the study reported in Paper II in light of flood risk reduction, we possibly also have to deal with hazard as well as vulnerability. Actually, at a local level, it is impossible to change the hazard itself, in terms of reduction of the rainfall amount. Anyway, this study did not focus on particular measures, but the overall theme is the *timing* of preventive actions, which should be linked to the nature of the hazard itself. Additionally, public emergency preparedness and early warning systems as well as ensuring individuals' access to information of the threat, can all be seen as contributing to reduced vulnerability to floods.

The work reported in Paper III can be associated with Exposure, according to the risk triangle (see Figure 4 in Section 2.3). Excluding the dynamic factors as rainfall and flow is a simplification of the actual circumstances when flooding occurs. This study did not grade the range of the floods or distinguish between surface or sewer conditions as the main cause of the flooding. However, the idea was to develop a tool based on relatively simple and 'neutral' criteria. If an address, identified by this method is indicated as exposed to floods, it might be impossible to reduce the physical exposure of the object itself. Nevertheless, awareness of this threat can induce precautions, which make people less vulnerable to future floods.

The work reported in Paper IV can be considered as a part of a socio-economic analysis. This study intended to measure the welfare loss caused by insecurity to floods in monetary terms, regardless of overall risk. Nevertheless, if the outcome of the study is applied for practical purposes aiming to reduce risk, there are still connections to the concepts in the risk triangle. In Paper IV particularly two significant variables, DistantFlood and OwnExperience, have a conjunction to Exposed, as respondents' insecurity are grounded in real events. On the other hand, for individuals, insecurity in itself can be a burden, in terms of worrying about the impacts of flooding, such as real estate value loss, additional clean-up work, vermin in the basement etc., even though they have no experience. The outcome of questions like *feeling* exposed or annoyed can also reveal concerned people with more 'intangible' sufferings as e.g. sense of inability to cope with floods, concerns about future climate effects etc. This can potentially identify people vulnerable to floods. Thus, from a risk perspective, risk reduction can simply be achieved by granting people access to more information and/or implementation of small scale preventive measures.

Whether each study fits into the basic and core concepts in the risk triangle, is not essential for the overall conclusions. As mentioned, there are no precise definitions of Hazard, Exposure and Vulnerability. However, if the area of the triangle presents the total risk, the area can be reduced by 'attacking' one or several sides. Then, this becomes a visualization of the fact that there are multiple pathways towards the ultimate goal, flood risk reduction.

5.4 Overall conclusions

The basic objectives for this study were to contribute knowledge and develop methods from non-engineering disciplines, with the intention to create more public engagement and awareness of the urban flood issue.

The first study confirmed that urban flood management in Norway, and the rest of Scandinavia as well, is still strongly associated with an engineering culture. Paper I pictured the improvement of drainage and sewer system as a continuous process. It was pointed out that quantitative targets to reduce the number of floods affecting individuals can make this issue more tangible. By quantifying the damages in terms of the annual number of flooded houses, annual cost etc., progress and goal achievement should be possible to evaluate. Paper I also indicated that unclear requirements could be one reason for the dominating use of unilateral and traditional methods for improvement of the sewer systems in Norway.

The overriding issue in Papers II, III and IV was to apply innovative tools to complement traditional engineer-solutions related to urban flood management. The idea was further then that techniques from non-engineering disciplines, can enforce interdisciplinary collaboration and increased awareness of the urban flood challenge. Additionally, these studies intended to apply techniques and processes that have the power to accelerate the transition to more use of sustainable methods aiming to reduce the urban flood risk.

Recent research support the findings in these articles. Still, problems are attacked with ideas, techniques and solutions from single disciplines and not by applying the interdisciplinary approach. This point of view is supported by studies from Jeffrey and Seaton (2004), Brown and Keath (2008), Brown et al. (2009) and (Cettner et al., 2014). They all apply a framework consisting of ‘four A-attributes’ called: Awareness–Association–Acquisition–Application as a starting point for recipients, when aiming for a successful implementation of changes, like a shift towards sustainable water management. Furthermore, there is a need to facilitate processes were multi-stakeholders come together to discuss urban flood issues. The importance of having processes that engage the local communities is emphasized (Sörensen et al., 2016, Zhou, 2014, Cettner et al., 2014). The tools and methods applied in this work can contribute to push these processes forward.

However, Papers II, III and IV all focused on urban floods based on user experiences; still different approaches in the way of reducing the risk were applied. An extensive set of factors are influencing the assessment of urban flood risk. It was pointed out that it is impractical to determine the exact level of risk, which speaks in favour of using a qualitative approach using the so-called risk triangle, where the terms Hazard, Exposure and Vulnerability are introduced.

Another possible way to distinguish between the papers is: Paper II was largely all about timing measures. In Paper III it was focused on the places that might be affected, while Paper IV introduced the human dimension in terms of insecurity. In summary, this is also about:

- *WHEN* - Importance of timing emergency preventive measures
- *WHERE* - Importance of identifying the most exposed area
- *WHO* – Importance of being aware of the insecurity people experience when it comes to urban flooding

All aspects underline the multifaceted and complex nature of the urban flood challenge.

This work has shown that that bringing in the citizens flood experience by using statistical tools as Principal Component Analysis, Partial Least Squares Regression, Ordinary Least Squares and Probit models can be useful supplements to hydraulic models. The most suitable tool is selected on the basis of both purpose and available data. To increase the validity of the statistical outcome from the analysis, one have to use a large number of samples and variables in the studies. On the other hand, these studies were all considered as explorative analyses and restricted to the case area, aiming for new ideas and testing new tools and techniques. Obviously, phenomenon pointed out in this work initiate important discussions, and the models can be further improved by more detailed analyses and larger samples.

The increased urban flood challenge is considered as a result of climate changes, in addition to rapid urbanization and aging pipe systems. This work can be regarded as examples or alternatives aiming to raise awareness of the increased risk for this. The outcome presented in each of the papers can be seen as standalone methods. In practice they can also be combined with other methods and attack the urban flood challenge from different angels.

References

AALL, C., ØYEN, C., HAFSKJOLD, S., ALMÅS, A., GROVEN, K. & HEIBERG, E. 2011. *Klimaendringers konsekvenser for kommunal og fylkeskommunal infrastruktur Delrapport 5 [Climate change and the consequences for local and regional infrastructure. Subreport 5]*.

AMRAM, M. & KULATILAKA, N. 1999. *Real options: managing strategic investment in an uncertain world,* Boston, Mass., Harvard Business School Press.

ANTHONISEN, U., INGE, F., HOVGAARD, J., JACOBSEN, P. & STEEN MIKKELSEN, P. 1992. Lokal afledning af regnvand [Local stormwater disposal]. *Spildevandsforskning fra Miljøstyrelsen.* Copenhagen, Denmark: Miljøstyrelsen.

ARNBJERG-NIELSEN, K., WILLEMS, P., OLSSON, J., BEECHAM, S., PATHIRANA, A., GREGERSEN, I. B., MADSEN, H. & NGUYEN, V. T. V. 2013. Impacts of climate change on rainfall extremes and urban drainage systems: a review. *Water Science and Technology,* 68**,** 16-28.

ASHLEY, R., NEWMAN, R., MOLYNEUX-HODGSON, S. & BLANKSBY, J. 2008. Active learning: building the capacity to adapt urban drainage to climate change *11th International Conference on Urban Drainage.* Edinburgh, Scotland, UK,.

ASHLEY, R. M., CETTNER, A., VIKLANDER, M., WALKER, L., SHARP, L. & E., W. 2011. Overcoming barriers in the transition from piped to alternative drainage systems. *2nd International Conference of Sustainability Transitions, June 13-15, 2011.* Lund University, Lund, Sweden.

BATEMAN, I. 2002. *Economic valuation with stated preference techniques: a manual,* Cheltenham, Elgar.

BOARDMAN, A. E. 2011. *Cost-benefit analysis: concepts and practice,* Boston, Prentice Hall.

BOS, J. J. & BROWN, R. R. 2012. Governance experimentation and factors of success in socio-technical transitions in the urban water sector. *Technological Forecasting and Social Change,* 79**,** 1340-1353.

BOTZEN, W. J. W., AERTS, J. C. J. H. & VAN DEN BERGH, J. C. J. M. 2009. Willingness of homeowners to mitigate climate risk through insurance. *Ecological Economics,* 68**,** 2265-2277.

BRAGA, B. P. F. 1999. Non-structural flood control measures – introductory notes for a special issue of urban waters. *Urban Water,* 1**,** 112.

BROWN, R., FARRELLY, M. & KEATH, N. 2009. Practitioner Perceptions of Social and Institutional Barriers to Advancing a Diverse Water Source Approach in Australia. *International Journal of Water Resources Development,* 25**,** 15-28.

BROWN, R. R. & KEATH, N. A. 2008. Drawing on social theory for transitioning to sustainable urban water management: Turning the institutional super-tanker. *Australasian Journal of Water Resources,* 12**,** 73-83.

BROWN, R. R., SHARP, L. & ASHLEY, R. M. 2006. Implementation impediments to institutionalising the practice of sustainable urban water management. *Water Science and Technology,* 54**,** 415-422.

BUTLER, C. & PIDGEON, N. 2011. From 'Flood Defence' to 'Flood Risk Management': Exploring Governance, Responsibility, and Blame. *Environment and Planning C: Government and Policy,* 29**,** 533-547.

CAMO 2015. The Unscrambler - User Manuals

CARRICO, N., COVAS, D. I. C., ALMEIDA, M. C., LEITAO, J. P. & ALEGRE, H. 2012. Prioritization of rehabilitation interventions for urban water assets using multiple criteria decision-aid methods. *Water Science and Technology,* 66**,** 1007-1014.

CETTNER, A. 2012. *Overcoming Inertia to Sustainable Stormwater Management Practice.* PhD-thesis, Luleå University of Technology, Sweden.

CETTNER, A., ASHLEY, R., HEDSTRÖM, A. & VIKLANDER, M. 2014. Assessing receptivity for change in urban stormwater management and contexts for action. *Journal of Environmental Management,* 146**,** 29-41.
CETTNER, A., SODERHOLM, K. & VIKLANDER, M. 2012. An Adaptive Stormwater Culture? Historical Perspectives on the Status of Stormwater within the Swedish Urban Water System. *Journal of Urban Technology,* 19**,** 25-40.
CHATTERTON, J., VIAVATTENE, C., MORRIS, J., PENNING-ROWSELL, E. & S., T. 2010. The cost of the summer 2007 floods in England. *In:* DEFRA, D. F. E., FOOD AND RURAL AFFAIRS (ed.).
CHOCAT, B., ASHLEY, R., MARSALEK, J., MATOS, M. R., RAUCH, W., SCHILLING, W. & URBONAS, B. 2007. Toward the Sustainable Management of Urban Storm-Water. *Indoor and Built Environment,* 16**,** 273-285.
CRICHTON, D. 1999. *The Risk Triangle*.
CRICHTON, D. 2012. *Flood plain speaking* [Online]. Available: http://www.cii.co.uk/knowledge/claims/articles/flood-plain-speaking/16686 [Accessed 26 April 2017].
DAWSON, R., SPEIGHT, L., HALL, J., DJORDJEVIC, S., SAVIC, D. & LEANDRO, J. 2008. Attribution of flood risk in urban areas. *Journal of Hydroinformatics,* 10**,** 275-288.
DE HAAN, J. & ROTMANS, J. 2011. Patterns in transitions: Understanding complex chains of change. *Technological Forecasting and Social Change,* 78**,** 90-102.
DEFRA 2004. *The Appraisal of Human-related Intangible Impacts of Flooding*, Department for Environment, Food and Rural Affairs.
DEFRA 2005. Making space for water, Taking forward a new Government strategy for flood and coastal erosion risk management in England. Department for Environment, Food and Rural Affairs.
DEFRA 2006. *R&D outputs: flood risks to people : phase 2 : the flood risks to people methodology*, Department for Environment, Food and Rural Affairs.
DIXIT, A. K. & PINDYCK, R. S. 1995. THE OPTIONS APPROACH TO CAPITAL-INVESTMENT. *Harvard Business Review,* 73**,** 105-115.
DOUGLAS, I. 2000. Fluvial Geomorphology and River Management. *Australian Geographical Studies,* 38**,** 253-262.
ESBENSEN, K. H., GUYOT, D. & WESTAD, F. 2000. *Multivariate data analysis - in practice: an introduction to multivariate data analysis and experimental design,* Oslo, Camo.
FARAHANI, H. A., RAHIMINEZHAD, A., SAME, L. & IMMANNEZHAD, K. 2010. A Comparison of Partial Least Squares (PLS) and Ordinary Least Squares (OLS) regressions in predicting of couples mental health based on their communicational patterns. *Procedia - Social and Behavioral Sciences,* 5**,** 1459-1463.
FARAM, M. G., ASHLEY, R. M., CHATFIELD, P. R. & ANDOH, R. Y. G. 2010. Appropriate drainage systems for a changing climate. *Proceedings of the Institution of Civil Engineers - Engineering Sustainability,* 163**,** 107-116.
FINANCE NORWAY. 2017a. *Forklaring til kodene i VASK (Vannskaderegisteret)[Explanation of the codes in VASK (National Register of Water Damages)]* [Online]. Available: https://vask.fno.no/OmKoder.aspx [Accessed 2 March 2017].
FINANCE NORWAY. 2017b. *VASK- Vannskadestatistikk [VASK-National Register of Water Damages]* [Online]. Available from: https://www.finansnorge.no/statistikk/skadeforsikring/vask/. [Accessed 2 March 2017].
FLETCHER, T. D., SHUSTER, W., HUNT, W. F., ASHLEY, R., BUTLER, D., ARTHUR, S., TROWSDALE, S., BARRAUD, S., SEMADENI-DAVIES, A., BERTRAND-KRAJEWSKI, J.-L., MIKKELSEN, P. S., RIVARD, G., UHL, M., DAGENAIS, D. & VIKLANDER, M. 2015. SUDS, LID, BMPs, WSUD and more – The evolution and application of terminology surrounding urban drainage. *Urban Water Journal,* 12**,** 525-542.
FRASER, E. D. G., DOUGILL, A. J., MABEE, W. E., REED, M. & MCALPINE, P. 2006. Bottom up and top down: Analysis of participatory processes for sustainability indicator identification as a

pathway to community empowerment and sustainable environmental management. *Journal of Environmental Management,* 78**,** 114-127.
FREDRIKSTAD MUNICIPALITY 2007. *Overvannsrammeplan [Master plan for Drainage and Storm water]*. *In:* FREDRIKSTAD MUNICIPALITY (TECHNICAL DIVISION) (ed.).
GEELS, F. W. 2006. The hygienic transition from cesspools to sewer systems (1840-1930): The dynamics of regime transformation. *Research Policy,* 35**,** 1069-1082.
GERSONIUS, B., ASHLEY, R., PATHIRANA, A. & ZEVENBERGEN, C. 2013. Climate change uncertainty: building flexibility into water and flood risk infrastructure. *Climatic Change,* 116**,** 411-423.
GOULDBY, B. & SAMUELS, P. 2005. Language of Risk PROJECT DEFINITIONS. *In:* FLOODSITE, U. (ed.) *Integrated Flood Risk Analysis and Management Methodologies.*
GOVERNMENT N 2015. NOU 2015:16 Overvann i byer og tettsteder- som problem og ressurs [Storm water in cities and towns - As a problem and resource}. *In:* MINISTRY OF CLIMATE AND ENVIRONMENT (ed.).
GOVERNMENT UK 2004. Foresight Future Flooding. *In:* TECHNOLOGY, O. O. S. A. (ed.).
GRANN, S. L. 2011. *Utrygghet for flom - en betinget verdsettingsstudie [Anxiety for floods - A contingent valuation study]* Master thesis NMBU.
HARDLE, W. & SIMAR, L. 2007. *Applied Multivariate Statistical Analysis , 2nd edition*.
HARREMOES, P. 2002. Integrated urban drainage, status and perspectives. *Water Science and Technology,* 45**,** 1-10.
HARREMOËS, P. 2003. Ethical aspects of scientific incertitude in environmental analysis and decision making. *Journal of Cleaner Production,* 11**,** 705-712.
INDAHL, U. G., MARTENS, H. & NÆS, T. 2007. From dummy regression to prior probabilities in PLS-DA. *Journal of Chemometrics,* 21**,** 529-536.
IPCC 2012. Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. *In:* FIELD, C. B., V. BARROS, T.F. STOCKER, D. QIN, D.J. DOKKEN, K.L. EBI, M.D. MASTRANDREA, K.J. MACH, G.-K. PLATTNER, S.K. ALLEN, M. TIGNOR, AND P.M. MIDGLEY (EDS.) (ed.).
JACKSON, J. E. 1991. *A User's Guide to Principal Components*.
JEFFREY, P. & SEATON, R. A. F. 2004. A Conceptual Model of 'Receptivity' Applied to the Design and Deployment of Water Policy Mechanisms. *Environmental Sciences,* 1**,** 277-300.
JHA, A. K., BLOCH, R. & LAMOND, J. 2012. *Cities and flooding: a guide to integrated urban flood risk management for the 21st century*, World Bank Publications.
JOLLIFFE, I. T. 2002. *Principal Component Analysis, Second Edition*.
KAŹMIERCZAK, A. & CAVAN, G. 2011. Surface water flooding risk to urban communities: Analysis of vulnerability, hazard and exposure. *Landscape and Urban Planning,* 103**,** 185-197.
KENNEDY & LEWIS 2007. Attaining the most sustainable solution in stormwater control in England and Wales. *LESAM 2007.* 2nd Leading Edge Conference on Strategic Asset Management Lisbon, Portugal October 17-19, 2007.
KRISTROM, B. & RIERA, P. 1996. Is the income elasticity of environmental improvements less than one? *Environmental and Resource Economics,* 7**,** 45-55.
LINDHOLM, O. & BJERKHOLT, J. 2010. Konsekvenser av flomskader i byer som følge av klimaendringer [Consequences of flooding in cities due to Climate Changes]. Available: http:/www.nmbu.no/institutter/imt/forskning-ved-imt/514.
LINDHOLM, O., ENDRESEN, S., THOROLFSSON, S., SÆGROV, S., JAKOBSEN, G. & L., A. 2008. *Veiledning i klimatilpasset overvannshåndtering [Guidelines for climate adapted stormwater management],* Hamar, Norway, Norsk Vann BA.
LINDLEY, S. J., HANDLEY, J. F., THEURAY, N., PEET, E. & MCEVOY, D. 2006. Adaptation Strategies for Climate Change in the Urban Environment: Assessing Climate Change Related Risk in UK Urban Areas. *Journal of Risk Research,* 9**,** 543-568.
MACINNES, J. 2016. *An Introduction to Secondary Data Analysis with IBM SPSS Statistics*, SAGE Publications.

MARDIA, K. V. 1979. *Multivariate analysis / K.V. Mardia, J.T. Kent, J.M. Bibby,* London ; New York, Academic Press.

MARSALEK, J. & CHOCAT, B. 2002. International Report: Stormwater management. *Water Science and Technology,* 46**,** 1-17.

MESSNER, F., PENNING-ROWSELL, E., GREEN, C., MEYER, V., TUNSTALL, S. & VAN DER VEEN, A. 2007. Evaluating flood damages: Guidance and recommendations on principles and methods. http://www.floodsite.net/html/partner_area/project_docs/T09_06_01_Flood_damage_guidelines_D9_1_v2_2_p44.pdf.

MUNDA, G. 2003. Social multi-criteria evaluation: Methodological foundations and operational consequences. *European Journal of Operational Research*

NASH, M. S. & CHALOUD, D. J. 2011. Partial Least Square Analyses of Landscape and Surface Water Biota Associations in the Savannah River Basin. *ISRN Ecology,* 2011**,** 11.

NAVRUD, S. 2005. Value transfer and environmental policy. *Environmental and Resource Economics 2004/2005,* p. 189-212.

NAVRUD, S. & MAGNUSSEN, K. 2013. *Valuing the Impacts of Natural Disasters and the Economic Benefits of Preventing them. Chapter 3 (p. 57-79) in Guha-Sapir, D. & I. Santos (eds.) The Economic Impacts of Natural Disasters.* .

NIE, L., LINDHOLM, O., LINDHOLM, G. & SYVERSEN, E. 2009. Impacts of climate change on urban drainage systems - a case study in Fredrikstad, Norway. *Urban Water Journal,* 6**,** 323-332.

NTEGEKA, V., WILLEMS, P., BAGUIS, P. & ROULIN, E. 2008. Climate change impact on hydrological extremes along rivers and urban drainage systems. Summary report Phase 1: Literature review and development of climate change scenarios. *In:* BELGIAN SCIENCE POLICY – SSD RESEARCH PROGRAMME, C.-H. (ed.). K.U.Leuven – Hydraulics Section & Royal Meteorological Institute of Belgium.

NYEGGEN, E., GJENSIDIGE FORSIKRING 2007. Klimaendringene - nye utfordringer for forsikring? [*Climate change - new challenges for the insurance industry?]*.

O'SULLIVAN, J. J., BRUEN, M., PURCELL, P. J. & GEBRE, F. 2012. Urban drainage in Ireland - embracing sustainable systems. *Water and Environment Journal,* 26**,** 241-251.

PÉREZ, N. F., FERRÉ, J. & BOQUÉ, R. 2009. Calculation of the reliability of classification in discriminant partial least-squares binary classification. *Chemometrics and Intelligent Laboratory Systems,* 95**,** 122-128.

RASMUSSEN, J. Klimatilpasning i København - Skybrud [Adaption to climate change in Copenhagen - cloudburst]. *In:* NTVA, ed. Teknisk naturvitenskapelig kunnskap i samfunnssikkerhetsarbeid, 2014 Trondheim.

REFSGAARD, J. C., ARNBJERG-NIELSEN, K., DREWS, M., HALSNAES, K., JEPPESEN, E., MADSEN, H., MARKANDYA, A., OLESEN, J. E., PORTER, J. R. & CHRISTENSEN, J. H. 2013. The role of uncertainty in climate change adaption strategies - a Danish water management example. *Mitigation and Adaptation Strategies for Global Change,* 18**,** 337-359.

RERIS, R. & BROOKS, P. Principal Component Analysis and Optimization: A Tutorial. 14th INFORMS Computing Society Conference, 2015. 212-225.

RSTUDIO TEAM. 2015. *RStudio: Integrated Development for R. RStudio, Inc., Boston, MA URL* [Online]. Available: https://www.rstudio.com/ [Accessed 16 June 2017].

SEMADENI-DAVIES, A., HERNEBRING, C., SVENSSON, G. & GUSTAFSSON, L.-G. 2008a. The impacts of climate change and urbanisation on drainage in Helsingborg, Sweden: Suburban stormwater. *Journal of Hydrology,* 350**,** 114-125.

SEMADENI-DAVIES, A., HERNEBRING, C., SVENSSON, G. & GUSTAFSSON, L. G. 2008b. The impacts of climate change and urbanisation on drainage in Helsingborg, Sweden: Combined sewer system. *Journal of Hydrology,* 350**,** 100-113.

SFT 1982. Veiledning ved infiltrasjon av overvann – metoder og tekniske løsninger (Guidelines for infiltration of stormwater - methods and technical solutions). Oslo, Norway: Statens Forurensingstilsyn [Norwegian Pollution Control Authority].

SHARMA, D. 2008. Sustainable Drainage System (SuDs) for Stormwater Management: A Technological and Policy Intervention to Combat Diffuse Pollution. *11th International Conference on Urban Drainage.* Edinburgh, Scotland, UK, 31 August - 5 September 2008

SMITH, G. 2003. Flash Flood Potential: Determining the Hydrologic Response of FFMP Basins to Heavy Rain by Analyzing Their Physiographic Characteristics. *In:* CENTER, N. C. B. R. F. (ed.).

SSB. 2012. *Kommunalt avløp 2012* [Online]. Statistics Norway SSB. Available: Available online: https://www.ssb.no/natur-og-miljo/statistikker/var_kostra/ [Accessed 26 March 2014].

SSB. 2016a. *Population´s level of education, 1 October 2015* [Online]. Available: https://ssb.no/en/utdanning/statistikker/utniv [Accessed 4 December 2016].

SSB. 2016b. *Tax statistics for personal tax payers, 2015, preliminary figures* [Online]. Available: https://www.ssb.no/en/inntekt-og-forbruk/statistikker/selvangivelse [Accessed 4 December 2016].

SØDAL, S. 2005. Real options in theory and practice (english version). *Økonomisk forum* nr 9 2005.

SÖRENSEN, J., PERSSON, A., STERNUDD, C., ASPEGREN, H., NILSSON, J., NORDSTRÖM, J., JÖNSSON, K., MOTTAGHI, M., BECKER, P., PILESJÖ, P., LARSSON, R., BERNDTSSON, R. & MOBINI, S. 2016. Re-Thinking Urban Flood Management—Time for a Regime Shift. *Water,* 8**,** 332.

TIPPETT, J. & GRIFFITHS, E. 2007. New Approaches to Flood Risk Management ? Implications for Capacity-Building. *Advances in Urban Flood Management.* Taylor & Francis.

TOBIAS, R. D. An introduction to partial least squares regression. Proc. Ann. SAS Users Group Int. Conf., 20th, Orlando, FL, 1995. Citeseer, 2-5.

VAN LUIJTELAAR, H., GASTKEMPER, H. G. & BEENEN, A. S. Heavier Rainfall Due to Climate Change: How to deal with effects in urban areas 11th International Conference on Urban Drainage, 2008 Edinburgh, Scotland, UK.

VAV 1983. Lokalt omhändterande av dagvatten [Local stormwater disposal]. *In:* SVENSSON, G. (ed.). Stockholm, Sweden: Svenska vatten och avloppsverkföreningen [The Swedish Water & Wastewater Association].

VENABLES, W. N., SMITH, D. M. & TEAM, R. D. C. 2009. *An Introduction to R*, Network Theory.

VILLARREAL, E. L., SEMADENI-DAVIES, A. & BENGTSSON, L. 2004. Inner city stormwater control using a combination of best management practices. *Ecological Engineering,* 22**,** 279-298.

WILLEMS, P. 2012. *Impacts of climate change on rainfall extremes and urban drainage systems,* London, IWA publishing.

WISNER, B. 2004. *At Risk: Natural Hazards, People's Vulnerability and Disasters*, Routledge.

WONG, T. H. F. & EADIE, M. L. 2000. Water sensitive urban design - A paradigm shift in urban design. *Xth World Water Congress. Melbourne Vic Australia : Organising Cttee, Xth World Water Congress,.* Melbourne Vic Australia.

YIN, R. K. 2009. *Case Study Research: Design and Methods*, SAGE Publications.

ZEVENBERGEN, C., VAN HERK, S., PUYAN, N. & GERSONIUS, B. 2007. Economic Feasibility Study of Flood Proofing Domestic Dwellings. *Advances in Urban Flood Management.* Taylor & Francis.

ZHANG, H. Y., SHI, Z. H., FANG, N. F. & GUO, M. H. 2015. Linking watershed geomorphic characteristics to sediment yield: Evidence from the Loess Plateau of China. *Geomorphology,* 234**,** 19-27.

ZHOU, Q. 2014. A Review of Sustainable Urban Drainage Systems Considering the Climate Change and Urbanization Impacts. *Water,* 6**,** 976.

ZOGG, J. & DEITSCH, K. 2013. The Flash Flood Potential Index at WFO Des Moines, Iowa. *In:* NATIONAL WEATHER SERVICE FORECAST OFFICE, U. S. (ed.).

Appended papers

Paper I

Geir Torgersen, Jarle T. Bjerkholt and Oddvar G. Lindholm (2014)
Addressing Flooding and SuDS when Improving Drainage and Sewerage Systems – A Comparative Study of Selected Scandinavian Cities

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Article

Addressing Flooding and SuDS when Improving Drainage and Sewerage Systems—A Comparative Study of Selected Scandinavian Cities

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Abstract: Pluvial flooding already challenges the capacity of drainage and sewerage system in urban areas in Scandinavia. For system owners this requires a stricter prioritization when improving the systems. Experts seem to agree that a regime shift from improving old combined sewers by piped solutions to more sustainable drainage systems (SuDS), must take place. In this paper results from an investigation amongst the largest cities in Norway, Denmark and Sweden concerning drivers and preferred methods for improving the old system are presented. The results indicate that Norway ranks flood prevention lower than the other Scandinavian countries. During the last decades, Norwegian authorities have had a strong focus on pollution from wastewater treatment plants (WWTP). The attention to drainage and sewerage system regarding flooding, water leaks, infiltration or pollution has been neglected. Renewal or rate of investment in relation to existing drainage and sewerage system is easy to register, and provides a measure of the activity. In order to optimize flood prevention, and may be promoting the use of SuDS, the cities should be required to measure the efficiency, either by monitoring or modeling the impact of stormwater to the system. Lack of such requirements from Norwegian authorities seem to be a plausible explanation to why Norwegian cities are less focused on flood prevention compared to Swedish and Danish cities.

Keywords: flood control; urban water; Scandinavia

1. Introduction

In a period with changing climate, impacts on both precipitation patterns and urban drainage will occur [1]. Increasing total rainfall and rainfall intensity will result in a greater load on the drainage and sewerage systems. These important infrastructure systems were designed and built years ago, and increased precipitation was not part of the design criteria. In addition, improper maintenance, aging *etc.* causes many problems. In Norway more than half of the systems are built before 1980 [2], and in central parts of the cities you will find the oldest systems.

Conventional piped drainage systems are designed for specific maximum flow rates and will be unable to meet the increase in the water volume [3]. Sustainable Urban Drainage Systems (SuDS) like ponds, open ditches, green roofs, *etc.* are in many countries made for stormwater treatment. In urban areas in Scandinavia the authorities only to a small extent have required stormwater treatment, and SuDS have then largely been considered as a flood prevention measure e.g., in Malmö, Sweden [4]. It has been shown e.g., in Denmark and Germany that decentralized solutions for stormwater handling are more flexible than conventional drainage systems. This flexibility is important when dealing with the uncertainties regarding future consequences [5–8]. An Irish study [9] concluded that although the benefits of SuDS are obvious, they are not sufficiently appreciated. The water and wastewater sector is considered to be very conservative [10,11], and the engineering culture is often referred to as a key barrier to implementing sustainable approaches in practice [11,12].

The Norwegian governmental report "Adaptation to a changing climate" released in December 2010, points to the many challenges that Norway is facing in relation to global climate change [13]. The future pace and scale of expected climate change are unknown, and implementing good and adaptable systems today is therefore a prerequisite for a less vulnerable Norway in the future. Urban areas are expected to be areas where the climate changes will be most apparent in everyday life [14]. Population growth and more impermeable surfaces due to more buildings, roads, parking lots, *etc.* are causing increasing strain on the drainage systems in the cities. A change to more sustainable stormwater systems in cities can reduce possible flooding in the urban environment [15].

Norwegian cities, like cities in many other countries, already experience challenges related to urban flooding. There are mainly three reasons for this: Climate changes, rapid urbanization and under-designed sewers [16]. The current pipes in the drainage systems in Norway cannot easily be replaced by larger pipes [17]. Heavy rain storms can lead to a runoff situation where the pipe capacity is exceeded, resulting in flooding events and backflow of wastewater into buildings and basements. This is already a major problem in several Norwegian cities [13]. So far, there has been limited development of *lokal overvannsdisponering-LOD (Local Stormwater Handling)*, which cover both infiltration and detention and is the Norwegian term that best corresponds with SuDS [18].

The organization of the wastewater sectors in the Scandinavian countries is comparable. Water distribution- and wastewater services in Scandinavian cities are all public services. The main systems are directly or indirectly owned by the municipalities and are managed either by their own employees or contracted professionals. The municipalities in all Scandinavian countries have for decades been encouraged by the national authorities to increase the use of SuDS [19–21]. The similarities in organization of the wastewater sector make it possible to investigate differences in how future challenges are met, and if this is reflected in the prioritization of the measures. There are some historical differences, while Denmark traditionally dimensioned their combined sewer for a 2 years flood recurrence interval before 1990 [21], Norwegian authorities recommended 5-years [22]. Regarding the responsibility for basement flooding from sewers, Norwegian municipalities have stricter obligations than in Sweden and Denmark [18].

Flood prevention measures involve many stakeholders with different perspectives although they are often seen in multidisciplinary cooperation. It is generally believed that climate changes are expected to cause more flooding in urban areas in the future [1,6,15,17], but how these changes will develop are not further discussed in this paper. Much of the impact of heavy rainfall in urban areas, are related to the drainage and sewerage system. The aim of this paper is then to investigate how the system owners' in practice are focusing on measures to reduce or prevent problems with pluvial flooding in urban areas e.g., backflow and flooding of basements. This includes measures either to avoid, delay or convey stormwater in the system. This is believed to be a challenge in urban areas worldwide, but as a basis for this study, a survey among the largest Scandinavian cities was carried out. Since this study deals with urban flooding, it was assumed that the largest cities were the most relevant selection for the study. The hypothesis was that the system owners in Norway, when improving old drainage and sewerage system, have little focus on flood-prevention, while other Scandinavian countries dealing with the same challenges rank flood prevention higher. In this paper, the term *improvement* is used independent of whether the methods are convential (renovating or renewing the piped sewers) or using SuDS. Summarized, the aims of this study are:

- How prioritized is flood prevention when Norwegian cities are improving their drainage and sewerage system? To what extent are SuDS the preferred method when improving the system?
- Are there any differences amongst the Scandinavian countries in how the cities or the national authorities meet this issue?

Key factors, such as technical conditions, incidents, economy and competence are believed to affect the priorities which are chosen. These factors are compared to identify possible causes for why flood prevention in urban areas is prioritized differently in the Scandinavian countries.

2. Background

The annual precipitation in Norway has increased by 20% during the 1900s, and some places it has increased with almost 2% per. 10 years some places since 1980 [13]. Extreme rainfall events in Norway are expected to increase slightly up to 2025, and then sharply towards 2050 [23]. In small catchments areas (20–50 ha), the maximum flow will normally occur during the summer months [24]. It is estimated that it will continue to rise with an average of 13% in the period 2071–2100 compared to 1961–1999 [16]. In the period 2071–2100, the intensity of the heaviest summer rains in Oslo is estimated to be 20% higher than today [25], while corresponding rains in the autumn are expected to become 40% higher than today. A comparison of extreme rainfall events with 24 hour durations from the past 100 years [26], show only small variations between the Scandinavian countries regardless of the return period and season. The western coast and mid-Norway experience the greatest extreme weather conditions in Scandinavia. However, only small differences are found when comparing specific measurements from the capitals of each country.

Precipitation and flooding in cities result in a number of social costs such as traffic disturbance, damage to infrastructure and buildings, sick leave due to infectious water, lost sales for businesses, pollution of drinking water and local recipients [24]. The insurance companies believe that these costs could increase by 40% or more over the next ten years. This estimate does not include conditions that are defined as natural disasters. The insurance companies are therefore working on a strategy to handle the expected increase in damages. They consider transferring more risk to both private homeowners and municipalities, if they are not willing to adapt to the assumed climatic changes [17]. There have been several court cases regarding heavy urban flood damages in recent years (e.g., Fredrikstad, Stavanger, Alta) [27,28]. All these cases have emphasized that insurance companies in the future will hold the municipalities more liable for flooding related to insufficient capacity of the mains. Not all costs are easy to determine, but from 1992 to 2007, Norwegian insurance companies paid 3000 million EUR in compensation for water damages. The expenses rose each year during the period, most likely due to frequent torrential rains and more rain in general. It is estimated that approximately 25% of these payments were due to flooded houses caused by insufficient urban drainage system [29].

In recent years, there have been several damages caused by heavy rain in Norway, for instance in Fredrikstad (August 2008) and in Drammen (August 2012), which resulted in major damages. Sweden has been less exposed to urban flooding, but some extreme events have caused significant social costs. Copenhagen in Denmark had a major rainfall in the summer of 2011. This is one of the clearest examples of extreme rainfall, which have consequences both for housing and infrastructure. Total insurance payments amounted to about 800 million EUR, distributed among approximately 80,000 cases [30,31].

Even though it is not possible to make an exact comparison, the above shows that there are many common challenges, and focus on flood prevention measures in urban areas should then be ranked almost equally in the Scandinavian countries.

3. Theory

The capacity of stormwater systems may be increased by new and larger pipes when old pipes cause problems with flooding, pollution, *etc.* This conventional method is no longer seen as sustainable [32], and if possible, it is increasingly replaced by non-piped solutions in more and more countries. How far this trend has been developed in different countries, vary widely, and great diversity is seen even within countries. In urban areas, it is not realistic to establish stormwater systems that completely consist of non-piped solutions. However, it is important to plan for an ever-increasing flood risk, and take into account that this will be an even greater challenge in the future. For a city, optimal measures will rarely consist of one single method, but a selection of sustainable solutions adapted for local conditions and requirements.

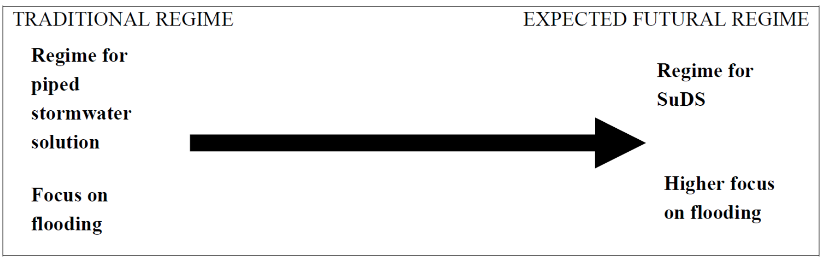
In the wastewater sector like many other sectors, a dominating way to solve a social subtask can be denoted as a *regime*, and such a regime is typical for the way we meet the societal needs [33]. Other regimes, which have a power are denoted *niche-regimes*, although they are not dominating the way that the societal needs are met. Niche regimes fundamentally challenge the dominant regime. A change in which a niche-regime emerges, and finally oust the dominant regime, may occur. The dominant regime will at any time be what protects the society's needs in the best way. This transitional change is denoted *regime shift*. The speed of this transition is influenced by a complex number of conditions, which drive the transition.

According to Ashley, *et al.* [34] the societal system is composed by a number of societal subsystems, and storm water management in cities is an example of such a social subsystem. The way to solve these challenges in cities, deals with two fundamentally different competing regimes. The developed part of the world is at different stages in the transition from the traditional storm water regime to other systems. The old regime, which in most cases also is the current regime, is to improve the system through piped solutions either by combined or separate systems. They state that the traditional piped solutions for handling storm water are the dominant regime in most cities. Changes in boundary conditions (*i.e.*, more flooding as a consequence of climate changes) may change the society's opinion and help the niche to develop. But a sudden increase in flooding events may be met by the decision makers by conventional renewing methods, because there is no time for untested methods as SuDS. Thus, the uptake of this niche may be delayed. However, the development of SuDS has come with an increasing focus at the possible impact of climate changes [35]. It is then assumed a transition towards the new and more flexible regime for storm water management will occur.

4. Methods

A general theoretical model [33], adapted by Ashley *et al.* [34], is used in this context. The increased attention to flooding as a target and SuDS as a preferred method to solve this is illustrated in Figure 1 as a transition line between the old and the new regime. According to Geels [36], the conceptual characteristics of a regime transformation is that the regime insiders gradually change their cognitive beliefs and behavioural norms.

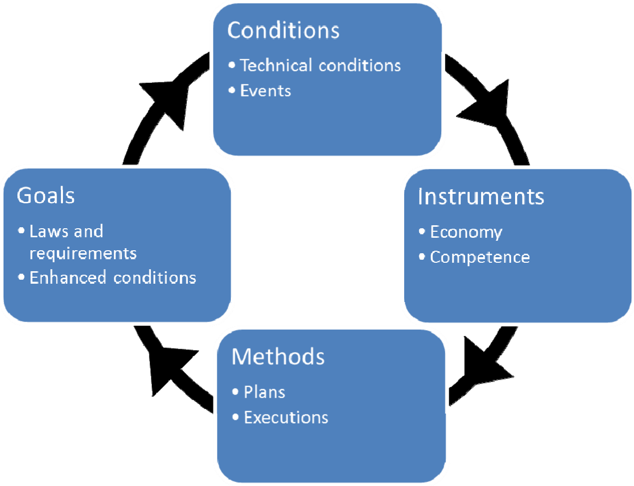
Figure 1. Transition line toward a sustainable urban drainage system (SuDS)-focused regime.



In step 1 of this survey a comparison between Norway and other Scandinavian countries was made, both in regard to the target for the improvement and the methods used.

The next step of this study was to make a model of factors that influence the present regime. These are the factors that combined can provide an explanation for the situation in each country, as shown in Figure 2. The factors are interrelated, and can be viewed as a continuous improvement process. Bos and Brown illustrated this in a broader perspective as "*Phases of governance experimentation leading* *to adaption in water governance structures…*". They mention this as strategic, tactical, operational and reflexive activities [12]. When a goal and a desired condition are achieved, new goals will be set and the process starts over again. The purpose of the model is to identify relationships between individual factors that may explain the differences, which are found in step 1.

Figure 2. Factors affecting flood and SuDS–focus—illustrated as a continuous process.



The model in Figure 2 can be used to compare any urban wastewater systems, (e.g., cities or companies). In this study, however, the model was used to compare the SuDS-focus in the Scandinavian countries. Within each factor, some quantitative and relevant parameters were identified and compared. In Figure 2, the term *Conditions* is used to describe the state of the technical facilities and the consequences of this condition. Renewal rate, the rate of combined systems or the amount of infiltrated water are all indicators for the conditions of the drainage and sewerage systems. In addition, water leaks are used as an indicator because this causes more water to infiltrate the drainage system, and affects the choice of method for repairing the system. In this study, the term *events* includes registered damages at insurance companies and economic costs of extreme rainfalls. *Instruments* are factors that can be utilized to change the conditions, e.g., the financial resources the owner is willing to spend and available expertise. This will mainly include professionals, but in an initial phase it may also include politicians and the citizens as well. The term *Methods* is used for the possible physical measures. These are again seen as a result of choices and strategies that have been taken to improve the condition of the system. The primary *Goal* in relation to this will be to reduce the risk of flooding. Within the wastewater sector, many of these goals are regulated by the EU Framework Directive, which is current legislation in all Scandinavian countries.

The survey was made out to capture trends, and it was designed to create a holistic view for the largest cities in Scandinavia. This study did not deal with the rate of change or the actual transition to a new regime. The results of the study were viewed in the light of the models described in Figures 1 and 2.

The wastewater plan, like other urban development plans, does not give a complete picture of how and why the cities prioritize new projects in practice [37]. The plans do not always show the preceding ideas and internal discussions among professionals. Therefore, the personnel managing the wastewater sector in each city were contacted and asked to take part in the survey. It was assumed that these persons have a great influence on the decisions for planning and implementing renewal projects. The largest cities are supposed to be the most relevant selection when it comes to urban flooding [38]. Smaller communities might be less vulnerable to flooding due to a higher proportion of natural green areas in the vicinity. However, they might also lack engineers to provide adequate solutions to flooding problems. Accordingly, small cities were excluded from the study, since these are expected to encounter different challenges than larger ones. In addition, the major cities in each country are expected to reflect the "national best practice" in relation to urban flooding. The current study analyses drivers and methods used by system owners for improving the drainage and sewerage systems, based on completed projects in the chosen reference year 2010.

Initially 10 Norwegian cities were visited in May–June 2012 and interviewed based on a qualitative study. This was done to get an overview of the state and to confirm the validation of the questions. Then the remaining 15 of the 25 largest cities were contacted and accepted to receive a questionnaire, which later was sent by mail. Respondents were asked questions about the improvements of existing drainage and sewerage system in a given reference year (2010). The key questions were triggering reasons and used methods when improving the system. In addition, they were asked questions about the condition of the system, availability of staff, and financial constraints. A similar study was done in Sweden and Denmark during winter 2012/2013. Based on the experience from Norway, three cities were visited and interviewed to confirm the questions. The rest of the cities among the 25 largest, were contacted and accepted participation in the questionnaire, which later was sent by mail.

From the survey in Norway, 22 of 25 cities (88%) responded. Similar numbers in Sweden were 14 of 25 (56%) and in Denmark 16 of 25 (64%). In addition to the questionnaire, quantitative data from national registers (Bedre VA (Norway), VASS (Sweden) and Danva benchmarking (Denmark)) for the reference year 2010 were collected. Even though the study was limited to the largest cities in the considered countries, the difference in population in the cities in the survey was substantial. Accordingly, weighting the results by the economy or population of the cities would result in a bias towards the trends in the largest cities (weighted answers from the smallest cities would have counted only 5% to 10% relative to the largest cities). Since the goal was to capture trends, the use of non-weighted averages for each country was selected.

There are obvious differences between the Scandinavian countries that must be taken into account before analyzing the results of the survey. The median number of inhabitants in the Norwegian cities that responded was approximately 47,300, while the corresponding numbers in Sweden and Denmark were 98,900 and 94,800, respectively. It is not reasonable to assume that the results from the larger cities are representative to smaller cities with less manpower, less financial resources and less population density. However, in this study there was no significant trend that the larger cities used other methods and had different reasons to improve the system than the smaller ones.

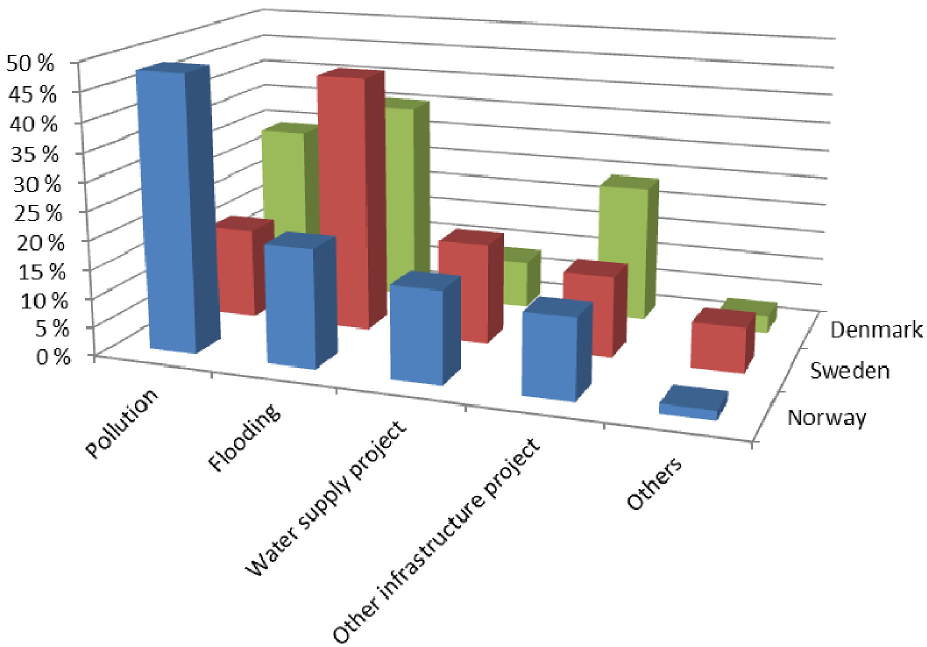
The results were related to the theory described above and presented in two steps. Step 1 was based on the responses to the questionnaire of selection process and methods for improvement projects in a given reference year. The results of this were used to calculate Norway's position in the transition towards a more sustainable storm water regime compared to Sweden and Denmark. In step 2 additional results from the survey, national benchmarking and literature review were used to find the underlying reasons for the differences between the considered countries.

5. Results

This study primarily investigates how cities were dealing with flood prevention. However, it also included an investigation regarding how measures in relation to existing drainage and sewerage system were undertaken. Measures are planned and conducted by the same professionals, and often carried out at the same time and need to be within a given budget. It was therefore relevant to compare the different triggers for improvement projects.

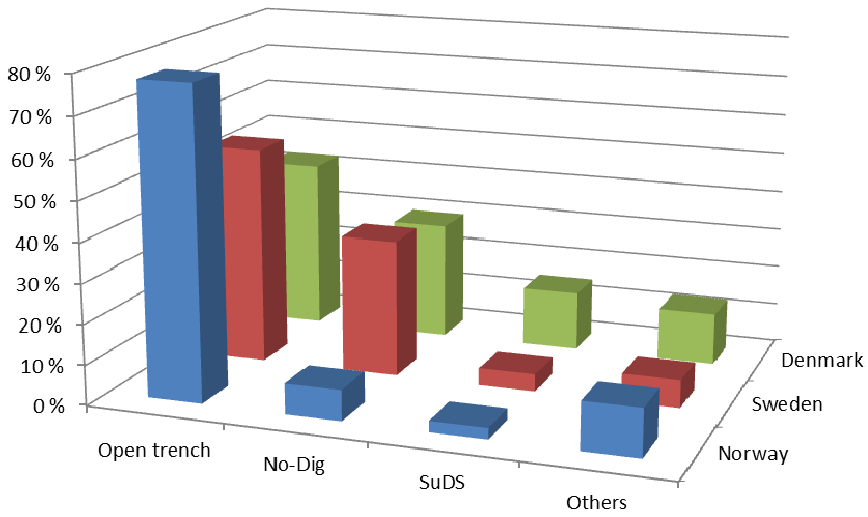
In step 1 of the survey, the engineers in the cities evaluated both the triggering cause and method in the reference year 2010. A project can have multiple purposes, and therefore the triggers could be somewhat more difficult to determine than the methods. However, they were requested to state what they believed were the main triggers. It is reasonable to assume that some causes require specific methods, thereby providing a close connection between them. It is accordingly appropriate to discuss these answers together. The distribution of causes triggering projects in the existing drainage and sewerage system in the largest Scandinavian cities in 2010, are shown in Figure 3.

Figure 3. Causes triggering improvement projects in existing drainage and sewerage systems in the largest Scandinavian cities in 2010.



When comparing this, life-cycle analysis (LCA) or other tools could have been useful [39], but in Figure 4 the projects are ranked by the financial investments. Open trench means digging up and replacing old sewers, while No-Dig covers relining, blocking or other possible methods for renewing the old pipe without digging. SuDS include non-piped solutions as ponds and open ditches trench, mainly built for flood protection. Compared to many other methods, SuDS are normally less capital intensive, and the amount spent on sustainable solutions is expected to be far lower than other methods such as open trench.

Figure 4. Methods used to improve existing drainage and sewerage systems in the largest Scandinavian cities 2010.



Some clear trends in relation to flooding were found in the survey and are shown in Figures 3 and 4:

- Compared to Sweden and Denmark, there were fewer cases in Norway where prevention of flooding was the triggering factor to wastewater projects. Pollution was reported to be the main reason for most drainage projects in Norway, far more important than in the other countries.
- Sustainable methods of stormwater management were used more frequently in Denmark than in the other countries.

In Figure 4 it is shown that SuDS was rarely used in Norway, in average it is only 3% which confirms previous research [18]. More than 80% of the Norwegian cities report that they did not use SuDS at all in 2010. Approximately 45% of the Swedish and 10% of the Danish cities reported the same. The findings indicate that both Denmark and Sweden are more focused on flood prevention measures.

Based on the results shown in Figures 3 and 4 it is not possible to see a correlation between focus on flooding and the use of SuDS. However, it seems to be a trend that Norwegian cities are more one-sided and traditional both in their targets and choice of methods to improve the drainage and sewerage system.

The limited focus on SuDS indicates that Norway is placed to the far left in Figure 1. Based on the same criteria, the survey indicates that Danish cities have made most progress in the development towards a more sustainable stormwater regime.

In step 2 of the study, the model in Figure 2 was discussed with an intention to explain the differences in step 1. Factors assumed to be relevant are shown in Table 1.

Table 1. Comparison of factors that may affect flooding and SuDS-focus.

Factors	Characteristics	Characteristics for Norwegian cities (N)	Characteristics for Swedish cities (S)	Characteristics for Danish cities (DK)
Conditions	Rate of combined sewers (2010) [1]	31%	13%	48%
	Renewal rate (2010) [1] per. Year [1]	0.74%	0.38%	1.07% (2000–2010)
	Number of basements flooding in houses caused by the drainage and sewerage system 2008–2010 [2]	6,000–6,500	6,000	6,000–9,000 (2008–2009), 20,000 (2010)
	Infiltrated water in the largest treatment plants in 2009 [3]	68%	58%	23%
	Leakage from drinking water networks 2010 [1]	43%	23%	9%
	Cities reporting lack of capacity [4]	32%	7%	7%
Instruments	Fee for a standard residential (2010) [1]	225 EUR per year	173 EUR	359 EUR
	Cities reporting good or adequate financial frames to improve the systems [4]	95%	42%	80%
	Cities reporting shortage of internal professionals [4]	59%	64%	23%
	Cities reporting shortage of available external expertise [4]	26%	29%	0%
Methods	Use of methods (ref. Figure 4) [4]	Most use of open trench	Less use of open trench, more use of No-Dig compared to N	Less use of open trench, more use of No-Dig compared to N
	Number of cities invested in SuDS (2010) [4]	18%	54%	92%
Goals	EU Water Framework Directive is the most relevant international legislation in the sector and is basically the same in all Scandinavian countries. In S the EU Flood directive is implemented for urban flooding, in contrast to N and DK.			
	N reports activity in the voluntary national benchmarking (Bedre VA) and required national reporting (KOSTRA). Both S and DK report the activities as in N. No reporting of emissions from transport system is required in N. Most of the cities in S and DK report emissions from all CSOs. In S this is reported to the regional, and in DK to national environmental authorities.			

Notes: [1] Data from national benchmarking (Bedre VA, VASS, DANVA benchmarking) for the 25 largest cities in each country which have registrated data; [2] Comparable insurance data. For Norway and Denmark 2008–2010, for Sweden 2010 [40–42]; [3] According to Lindholm, *et al*. [43]; [4] Survey of the largest cities in Norway, Sweden and Denmark related to this paper.

6. Discussion

6.1. Conditions

When evaluating the technical condition of the drainage and sewerage systems in relation to flooding, it is relevant to compare the share of combined sewers. From Table 1 it can be seen that both Norway and Denmark have significantly more combined sewers than Sweden, and from Table 1 it can be seen that leakage from drinking water network is significantly higher in Norway compared to

Sweden and Denmark. Even if leaks from water pipes into sewers are unaffected by precipitation, it is relevant in this context, because it causes reduced capacity to handle extreme rainfall.

Infiltrated water is defined as any unwanted water entering the sewers and is, according to Lindholm *et al.* [43], higher in Norway than in the other Scandinavian countries. Much infiltrated water results in extra large flow during periods with heavy rainfall. As an additional question, the cities were requested to make subjective evaluations of the sewers. The responses fit well with the study of infiltrated water. Evaluated on the basis of capacity, the Norwegian cities are rather more pessimistic than in the other countries, and approximately 30% state capacity as poor/reduced. Among the Swedish and Danish cities, less than 10% report this.

An effect of poor condition of the systems is a high number of registered flood damages after large rainfall events. To identify challenges from urban flooding in Scandinavia, the number and cost of flooding from sewers registrated by insurance companies can be compared. From the Norwegian register of water related damages [40], the number of damages from 2008 to 2010 were about 6000–6500 per. year and with an estimated cost of *ca.* 35–40 million EUR each year. Statistics from Sweden the recent year [41] have estimated that these costs are 30–35 million EUR. Sweden is almost twice as densely populated as Norway. The number of damages due to lack of capacity of the drainage systems is low from the Swedish insurance companies' point of view [44]. Even if it is an increasing problem, it is not yet seen as a big challenge compared to other kind of damages. In Denmark there are statistics for cloudbursts [42], but this is not separated into the different kind of damages. In Denmark, the number and cost of damages was estimated to be at same level as Norway in 2008–2009, but it was more than doubled in 2010. However, this increase is probably linked to differences in spesific events, and not to the conditions of the systems.

Comparison of several parameters describing the current state indicate that Denmark has experienced more damages caused by some spesific incidents, while Norway has significantly greater challenges in terms of the technical conditions of the sewers than Sweden and Denmark.

6.2. Instruments

According to the selected instruments, the survey generally showed a more positive trend in Danmark. They were less conserned about the capacity and had fewer challenges in recruiting professionals than Norway and Sweden.

Both Sweden and Denmark have an opportunity to levy a separate stormwater fee [45,46], which may lead to consciousness for sustainable stormwater treatment. Sweden and Norway have significant lower fees than Denmark. The cities were asked whether they had sufficient financing to improve the drainage and sewerage systems in the reference year 2010. Although the Norwegian cities had lower fees than Denmark, the professionals in Norway are more positive to the available financial resources than the largest Danish cities. A comparison of instruments indicates that Norway has a challenge in recruiting enough professionals. There are also strong indications that they have lower ambitions in relation to what is sufficient economic framework to improve the system.

For the Swedish cities, it is a more significant correlation between low fees and dissatisfaction of the financial frames of the drainage and sewerage systems.

6.3. Methods

The results presented in Figure 4 indicate that replacing old pipes is far more common in Norway than in the other Scandinavian countries. This means that old combined systems were dug up and replaced with separate sewers. The method is both expensive and time consuming in urban areas, but is a safe method to reduce pollutant emissions, provided that all private service pipes in the area is in good condition or replaced at the same time. The municipal engineers in Norway are more satisfied with the financial framework than in the other countries. This may be the reason why they often choose to improve the system by open trench. Moreover, Table 1 shows that water leaks is such a big problem that in many ways the use of full digging is preferred and thus it is suitable to separate the system too.

In the survey, No-Dig-methods seemed to be little used as a renovation method in Norwegian cities in contrast to Sweden and Denmark. According to Lindholm [47] the largest cities in Norway have an ever increasing use of No-Dig as the preferred renovation method. Apart from that, water leaks can enforce open trenches; a possible explanation may be that Norway is less densely populated. Otherwise, there are no clear technical reasons why No-Dig-methods are less used in Norway than in Sweden and Denmark.

As mentioned above, SuDS are found to be significantly more frequently used in Denmark than Norway. One explanation may be that Denmark traditionally has greater need to restore stormwater to the natural environment, since 99% of drinking water sources in Denmark are groundwater. Accordingly, Denmark already has a tradition of SuDS planning since the 1990s, before the climate changes came into focus.

Methods for improving the wastewater system vary less in Norway than in the other countries. Uniform use of methods may mean that Norway has some extraordinary challenges which only can be solved by open trench. The water leaks from water supply network may be such a challenge. Another possibility is that the current and past requirements do not encourage varying methods in relation to the challenges that arise. As previously mentioned [10], the wastewater sector in Norway is known to be conservative. It may, in addition to shortage of professionals, be the reason why testing of more sustainable methods are prioritized lower than in Denmark.

6.4. Goals

EEC and national laws regulate flooding and damage from surface water in all Scandinavian countries. The Water Framework Directive aims at ensuring that all watercourses are returned to a natural state. The Flood Directive requires the responsible authority to do risk analysis to identify potential flood incidents. Actions that ensure the achievement of an acceptable level of risk should be taken by 2015. In Sweden, the EU Flood directive is implemented for urban flooding, in contrast to Norway and Denmark. In addition, there may be differences in national requirements and particularly in how they are practiced.

Both in Sweden [46] and Denmark [48], separate laws for the water- and wastewater sectors have been passed. In Norway, relevant acts governing the wastewater sector are integrated in several laws. The Planning and Building Act, the Water Resources Act and the Pollution Control Act are the most relevant laws [24,49]. Although sector laws have given the wastewater management increased attention in Sweden and Denmark, the short time since these laws were passed suggest that this is probably not the main explanation for why Norway has different priorities.

In terms of preventing flooding, it is particularly interesting to compare the requirements from the national authorities regarding the impact of stormwater to the drainage and sewerage system. The way in which the requirements from the authorities have been given and controlled appears to have varied since the 1990s. The investigation indicates that Norwegian cities, in the reference year 2010, have the same priority as they had before climate change became an issue.

Interestingly, the Norwegian pollution authority has not demanded monitoring or modeling the efficiency of the improvements in the network during the last 20 years. Accordingly, Norwegian cities have never had any incentives to monitor these themselves. Thus, it has not been possible to evaluate the impact of the measures that has been taken, nor is it clear whether the main reason for improvement was to achieve reduced pollution or flood control. Ever since the 1990s, the National authorities in Sweden and Denmark have had a greater focus on monitoring combined sewer overflows (CSO) from sewers than Norway. In Sweden, the overflow values were made public through the EMIR registry to the county administrative board [50]. It was demanded that the overflow volume from sewers which served WWTP designed for more than 500 pe (population equivalents), should be monitored [51]. In Denmark, this is reported by Danish Nature Agency [52]. It appears that the requirements to monitor overflow from transport systems have been the focus of the national authorities in both Sweden and Denmark. In contrast to Norway, this might have made the cities more aware that the emissions from transport systems should affect the priorities when deciding where and how measures are taken.

6.5. Considerations Concerning Improvement as a Continuous Process

In Figure 2, the development process is drawn as a circle, which illustrates that this is a continuous process. Accordingly, when a goal has been reached, for example by an implemented wastewater plan, better conditions are achieved. Thus, the process will commence with a new starting point, and new choices and priorities based on changed conditions will emerge. How to measure and compare the original and the improved condition of the drainage and sewerage system is significant, since this confirms whether the instruments and methods have been optimized.

An indication of the focus Norwegian authorities had in the 1990s is given by Bull [53]. In 1996, it was articulated in a speech by the junior minister in the Royal Norwegian Ministry of the Environment that the goal was to clean up the sewage sector in Norway by the year 2000. It was focused on how to finalize the separation of combined systems, and improving treatment plants within a few years. Guidelines from the regional environmental authorities [54,55] show that the quantitative requirements through the 1990s and 2000s applied only to overflow from wastewater treatment plants. According to Farestveit [56] the Norwegian authorities were concerned about overflow from CSOs in the 1990s, but unfortunately this attention declined in the 2000s.

The survey showed that Norwegian cities have less variation in the use of improvement methods. Open trench, which is a traditional method, was more frequently used in Norway than in the other Scandinavian countries. This fits the findings that Norway has limited internal personnel resources, but acceptable economic constraints. When Norwegian cities specify triggers for a specific project, this is probably based on the intentions for the project. Since loss from transport systems is seldom monitored, the assumption that one method provides a better condition is prevailing, e.g., separation is synonym to pollution reduction. It is difficult to verify to which extent the intended goal is achieved. Improvement projects in the wastewater system in Norway have mainly been reported by activities, e.g., renewal rate (meter pipe per year or % restoration per year) or the investment (amount of money per year). This focus has probably appeared because it is both easy to register and explain to the society. When a significant number of Norwegian cities reported that they currently face major challenges related to infiltration of water into the transport systems, which are recently renewed, there are reasons to question how they register achievement of goals. Lack of requirements may have led to the fact that overflow and other loss from the system have been unknown. Accordingly, the condition and the need for improvements are defined by other, simpler criteria. This may have led to an impression that method and activity are the main goals.

The state of the wastewater system seems to be significantly lower in Norway than in the other Scandinavian countries. There are already considerable challenges to manage increased rainfall. For all countries, and particularly for Norway, it is important to quantify the impact of what has being carried out. More focus on the requirements of measuring the impacts of prioritized projects will probably lead to a more sustainable stormwater management in Norway.

7. Conclusions

Current practice for prioritizing new projects in existing drainage and sewerage system in Scandinavia is shown in Figures 3 and 4. The study, which applies to the reference year 2010, indicates:

- Flood prevention measures are less important target in Norwegian cities compared to the other Scandinavian countries. The most important reason when prioritizing projects in the existing systems is reduction of pollution. In both Sweden and Denmark flooding is more frequently given as the reason for initiating and conduct improvement projects;
- Methods for sustainable urban drainage system (SuDS) are rarely used in Norway. Based on the amount of money invested, Denmark seems to have a higher utilization of SuDS-methods than cities in Sweden and Norway, where the same low rate of SuDS-measures are found. There are also differences in the number of cities, which use SuDS. The respondents from Denmark reports 93%, while the corresponding numbers in Sweden and Norway are 54% and 18%, respectively. Both climate prognoses and increase in insurance damages should indicate that the challenges in Norway are almost the same as in Sweden and Denmark. The condition of Norwegian wastewater system seems to be worse than the other Scandinavian countries. It is therefore reasonable to question why flood prevention and sustainable stormwater handling have such a low priority. The survey was done with reference to the year 2010. The heavy rain in Copenhagen 2 July 2011 or other incidents do not seem to explain the differences.

There are several reasons why Norway has not progressed as far as the other countries in relation to this issue:

- Denmark use groundwater for water supply. Therefore, the return of stormwater to the natural environment has been part of the Danish engineering culture even before it became the focus of climate changes and extreme weather. To a lesser extent, the same could be the case in Sweden. Norwegian cities use surface water for water supply and have more water resources. Therefore, the initiative for taking such considerations is smaller in Norway;
- Shortage of enough competent personnel both internally and in the external consultancy market, may lead to limited resources for innovation and analysis to find the optimal measures. The survey showed that in Norway the prioritization of new projects are done on the basis of the same considerations, and probably with the same methods, as before climate changes became an issue more than 10 years ago;
- There are indications that the Norwegian authorities' interest and actual requirements for the leakage of wastewater in general, and from the transport system in particular, have been lacking compared to the other countries since the 1990s.

To get a better view and more consciousness about the problem, the Norwegian authorities should introduce stricter demands for documentation of total overflow and leakage from the transport system. This can encourage the Norwegian cities to be more focused on the *impacts* of improvement projects rather than the *activity*. Over time, this can lead to a more sustainable stormwater management.

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Conflicts of Interest

The authors declare no conflict of interest.

References

1. Grum, M.; Jorgensen, A.T.; Johansen, R.M.; Linde, J.J. The effect of climate change on urban drainage: An evaluation based on regional climates model simulations. *Water Sci. Technol.* **2006**, *54*, 9–15.
2. SSB Kommunalt avløp 2012. Available online: https://www.ssb.no/natur-og-miljo/statistikker/var_kostra/ (accessed on 26 March 2014).
3. Sharma, D. Sustainable Drainage System (SuDs) for Stormwater Management: A Technological and Policy Intervention to Combat Diffuse Pollution. In Proceedings of the 11th International Conference on Urban Drainage, Edinburgh, UK, 31 August–5 September 2008; p. 10.
4. Villarreal, E.L.; Semadeni-Davies, A.; Bengtsson, L. Inner city stormwater control using a combination of best management practices. *Ecol. Eng.* **2004**, *22*, 279–298.

5. Peters, C.; Sieker, H.; Jin, Z.; Eckart, J. Deliverable 2.1.4 Assessing future uncertainties associated with urban drainage flexible systems—The COFAS method and tool. Available online: http://www.switchurbanwater.eu/outputs/pdfs/W2-1_GEN_MAN_D2.1.4_Assessing_future_uncertainties_urban_drainage_COFAS.pdf (accessed on 26 March 2014).
6. Arnbjerg-Nielsen, K.; Willems, P.; Olsson, J.; Beecham, S.; Pathirana, A.; Gregersen, I.B.; Madsen, H.; Nguyen, V.T.V. Impacts of climate change on rainfall extremes and urban drainage systems: A review. *Water Sci. Technol.* **2013**, *68*, 16–28.
7. Refsgaard, J.C.; Arnbjerg-Nielsen, K.; Drews, M.; Halsnaes, K.; Jeppesen, E.; Madsen, H.; Markandya, A.; Olesen, J.E.; Porter, J.R.; Christensen, J.H. The role of uncertainty in climate change adaption strategies—A Danish water management example. *Mitig. Adapt. Strateg. Glob. Chang.* **2013**, *18*, 337–359.
8. Sieker, H.; Helm, B.; Krebs, P.; Schlottmann, P.; Tränker, J. Flexibility—A planning criterion for stormwater management. In Proceedings of the 11th International Conference on Urban Drainage, Edinburgh, UK, 31 August–5 September 2008.
9. O'Sullivan, J.J.; Bruen, M.; Purcell, P.J.; Gebre, F. Urban drainage in Ireland—Embracing sustainable systems. *Water Environ. J.* **2012**, *26*, 241–251.
10. Aall, C.; Øyen, C.; Hafskjold, S.; Almås, A.; Groven, K.; Heiberg, E. Klimaendringenes konsekvenser for kommunal og fylkeskommunal infrastruktur. Delrapport 5. (Climate change and the consequences for local and regional infrastructure. Subreport 5). Available online: http://www.vestforsk.no/filearchive/r-ks-hindringsanalyse.pdf (accessed on 26 March 2014).
11. Harremoes, P. Integrated urban drainage, status and perspectives. *Water Sci. Technol.* **2002**, *45*, 1–10.
12. Bos, J.J.; Brown, R.R. Governance experimentation and factors of success in socio-technical transitions in the urban water sector. *Technol. Forecast. Soc. Chang.* **2012**, *79*, 1340–1353.
13. The Norwegian Ministry of Environment. Tilpassing til eit klima i endring NOU 2010:10 (Adaptation to a changing climate). Available online: http://www.regjeringen.no/upload/MD/Kampanje/klimatilpasning/Bilder/NOU/NOU-rapport/NOU201020100010000DDDPDFS.pdf (accessed on 13 December 2013).
14. European Environment Agency. Urban adaptation to climate change in Europe, Challenges and opportunities for cities together with supportive national and European policies. Available online: http://www.eea.europa.eu/publications/urban-adaptation-to-climate-change (accessed on 26 March 2014).
15. Semadeni-Davies, A.; Hernebring, C.; Svensson, G.; Gustafsson, L.G. The impacts of climate change and urbanisation on drainage in Helsingborg, Sweden: Combined sewer system. *J. Hydrol.* **2008**, *350*, 100–113.
16. Nie, L.; Lindholm, O.; Lindholm, G.; Syversen, E. Impacts of climate change on urban drainage systems—A case study in Fredrikstad, Norway. *Urban Water J.* **2009**, *6*, 323–332.
17. Lindholm, O.; Bjerkholt, J. Konsekvenser av flomskader i byer som følge av klimaendringer (Consequences of flooding in cities due to climate change). Available online: http://www.nmbu.no/institutter/imt/forskning-ved-imt/514 (accessed on 26 March 2014).
18. Langeland, E. *Implementering av Lokale Overvannsløsninger (Implementation of Local Stormwater Management)*; Norwegian University of Life Sciences: Ås, Norway, 2011; p. 67.

19. SFT Norway (Climate and Pollution Agency). *Veiledning ved Infiltrasjon av Overvann—Metoder og Tekniske Løsninger (Guidelines for Infiltration of Stormwater—Methods and Technical Solutions)*; Statens Forurensingstilsyn: Oslo, Norway, 1982.
20. Svenskt Vatten (The Swedish Water & Wastewater Association SWWA). *Lokalt omhändterande av dagvatten (Local stormwater disposal)*; Svenska vatten och avloppsverkföreningen: Stockholm, Sweden, 1983.
21. Anthonisen, U.; Inge, F.; Hovgaard, J.; Jacobsen, P.; Steen Mikkelsen, P. *Lokal afledning af regnvand (local stormater disposal)*; Miljøstyrelsen: Copenhagen, Denmark,1992.
22. Lindholm, O.G.; Engan, J.A.; Rapp, Ø.; Petersen-Øverleir, A.; Markhus, E. *Revurdering av beregningskriterier for avløpssystemer, flom i kommunale avløpssystem (Reconsidering the dimensioning criteria for the sewerage system)*; NIVA-Norsk Institutt for Vannforskning: Oslo, Norway, 2003.
23. Førland, E.J.; Alfnes, E. *Climate Change and Natural Disasters in Norway: An Assessment of Possible Future Changes*; Norwegian Meteorological Institute: Oslo, Norway, 2007.
24. Lindholm, O.; Endresen, S.; Thorolfsson, S.; Sægrov, S.; Jakobsen, G.; Aaby, L. *Veiledning i klimatilpasset overvannshåndtering (Guidance on climate adapted stormwater management)*; Norsk Vann BA: Hamar, Norway, 2008; Volume 162.
25. Nilsen, V. *Urban Drainage in the Face of Climate Change: Adaptation of Regional Climate Model Output for Rainfall-Runoff Simulations in Oslo, Norway*; Norwegian University of Life Sciences: Ås, Norway, 2008.
26. Agersten, S. *Analysis of Extreme Daily Precipitation and Return Periods in Norway and NORDKLIM Area*; Norwegian Meterological Institute: Oslo, Norway, 2002.
27. Lindholm, O.; Schilling, W.; Crichton, D. Urban Water Management before the Court: Flooding in Fredrikstad, Norway. *J. Water Law* **2006**, *17*, 204–209.
28. Ebeltoft, M. Naturskader og overvann i forsikring. Available online: http://www.sintef.no/uploadpages/282757/5_Klimatilpasning%20%20VA%20dagenen%20midt%20norge%2012%20sept.pdf (accessed on 26 March 2014).
29. Nyeggen, E. Gjensidige Forsikring Klimaendringene—Nye Utfordringer for Forsikring? (Climate Change—New Challenges for the Insurance Industry?) Available online: http://www.forsikringsforeningen.no/wp-content/uploads/2012/08/2007-Nyeggen.pdf (accessed on 26 March 2014).
30. The Danish Government, Sådan håndterer vi skybrud og regnvand, Handlingsplan for klimasikring av Danmark (How we deal with torrential rain and storm water, Action Plan for climate proofing in Denmark). Available online: http://www.klimatilpasning.dk/media/566642/klimahandlingsplan.pdf (accessed on 13 December 2013).
31. Johansen, N.B. Erfaringer fra 2 timers regnen i København (experiences from the 2-hours of rain in Copenhagen July 2, 2011). In *En blå/grønn fremtid—vårt ansvar—Overvannshåndtering, October 23–24, 2012*; Tekna: Gardermoen, Norway, 2012.
32. Kennedy, S.; Lewis, L. Attaining the most sustainable solution in stormwater control in England and Wales. In Proceedings of the LESAM 2007, 2nd Leading Edge Conference on Strategic Asset Management, Lisbon, Portugal, 17–19 October 2007.

33. De Haan, J.; Rotmans, J. Patterns in transitions: Understanding complex chains of change. *Technol. Forecast. Soc. Chang.* **2011**, *78*, 90–102.
34. Ashley, R.M.; Cettner, A.; Viklander, M.; Walker, L.; Sharp, L.; Westling, E. Overcoming barriers in the transition from piped to alternative drainage systems. In Proceedings of the 2nd International Conference of Sustainability Transitions, Lund University, Lund, Sweden, 13–15 June 2011.
35. Semadeni-Davies, A.; Hernebring, C.; Svensson, G.; Gustafsson, L.-G. The impacts of climate change and urbanisation on drainage in Helsingborg, Sweden: Suburban stormwater. *J. Hydrol.* **2008**, *350*, 114–125.
36. Geels, F.W. The hygienic transition from cesspools to sewer systems (1840–1930): The dynamics of regime transformation. *Res. Policy* **2006**, *35*, 1069–1082.
37. Cettner, A. *Overcoming Inertia to Sustainable Stormwater Management Practice*; Luleå University of Technology: Luleå, Sweden, 2012.
38. The International water association, Flood Types. Available online: http://www.iwawaterwiki.org/xwiki/bin/view/Articles/FloodTypesInundationTypes#HUrbanFlood (accessed on 13 December 2013).
39. Østerbø Sørumshagen, H.; Bjerkholt, J.T.; Lindholm, O.G. Bærekraftig rehabilitering av vann og avløpsnettet (Sustainable renovation of water- and wastewater system). *Vann* **2010** *3*, 357–371.
40. Finans Norge. VASK-vannskaderegisteret (Register of Water Damages). Available online: http://www.fno.no/Hoved/Statistikk/skadeforsikring/VASK (accessed 26 March 2014)
41. Olshammar, M.; Baresel, C. Vattenskador orsakade av baktryck i avloppssystemet—erfarenheteer, regler, hantering och tekniska løsninger (Water damage caused by back pressure in the sewerage system—experiences, rules, management and technical solutions). 2012. Available online: http://www.ivl.se/download/18.5c577972135ee95b56380001184/1362488385940/B2029.pdf (accessed on 13 December 2013).
42. Forsikring og pension. Vejrskader (Weather Damages). Available online: http://www.forsikringogpension.dk/temaer/klima/Documents/skybrudstal%20sept%202012.pdf (accessed on 13 December 2013).
43. Lindholm, O.G.; Bjerkholt, J.; Lien, O. Fremmedvann i nordiske avløpsledningsnett (Infiltrated water in Nordic sewer mains). *Vann* **2012**, *1*, 39–48.
44. Moberg, S. Senior Legal Advisor Insurance Sweden. Personal Information, 2013.
45. The Danish Government. Lov om afgift av spildevand (Wastewater Tax Act). Available online: https://www.retsinformation.dk/Forms/r0710.aspx?id=13236 (accessed on 13 December 2013).
46. The Swedish Government, Lag om allmänna vattentjänster (Public Water Services Act). Available online: http://www.notisum.se/rnp/sls/lag/20060412.HTM 2006 (accessed on 13 December 2013).
47. Lindholm, O. Norwegian Institute of Life Sciences, Ås, Norway. Personal Information, 2013.
48. The Danish Government. Lov om vandsektorens organisering og økonomiske forhold (Water Sector Reform Act). Available online: https://www.retsinformation.dk/Forms/r0710.aspx?id=125346 (accessed on 13 December 2013).
49. Sekse, T. *Klimatilpasningstiltak innen vann og avløp i kommunale planer (Climate change adaptation in water and wastewater in municipal plans)*; Norsk vann BA: Hamar, Norway, 2012.

50. Naturvårdsverket (Swedish environmental protection agency). Föreskrifter om kontroll av utsläpp till vatten-och markrecipient från anläggningar för behandling av avloppsvatten från tätbebyggelse (Regulations on the control of emissions to water and recipients from treatment plants of urban waste water). In *SNFS 1990:14 MS:32*; Available online: http://www.naturvardsverket.se/Documents/foreskrifter/nfs1990/SNFS1990_14k.pdf (accessed on 13 December 2013).
51. Naturvårdsverket (Swedish environmental protection agency) *Bräddning från avloppsledningar—Kontroll av bräddning och bräddningsmängder (Overflow from sewers—inspection of overflow and overflow volumes)*; Available online: http://www.naturvardsverket.se/Documents/allmrad/ar_93_6.pdf (accessed on 26 March 2014).
52. Naturstyrelsen (Danish Nature Agency). Punktkilder 2011 (Emission Points 2011). Available online: http://www.naturstyrelsen.dk/NR/rdonlyres/313C43EE-D4D2-4513-9E35-C5740DB435F3/0/Punktkilderapport2011.pdf (accessed on 26 March 2014).
53. Bull, B. VA-investeringer—Miljøtiltak Som Monner (Water and wastewater investments—Environmental measures that make a difference). Available online: http://www.regjeringen.no/nb/dokumentarkiv/regjeringen-brundtland-iii/md/Taler-og-artikler-arkivert-individuelt/1996/va-investeringer_-miljotiltak_som.html?id=261576 (accessed on 26 March 2014).
54. Fylkesmannen i Østfold (County Governor of Østfold). Vedlegg til kommunale utslippstillatelser. Unpublished work, 1992.
55. Fylkesmannen i Østfold (County Governor of Østfold). *Vedlegg til kommunale utslippstillatelser (Attachment to municipal emission permits)*; Fylkesmannen i Østfold Miljøvernavdelingen: Moss, Norway, 2001.
56. Farestveit, T. The Climate and Pollution Agency (KLIF). Personal Information, 2013.

Paper II

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CORRELATION BETWEEN EXTREME RAINFALL AND INSURANCE CLAIMS DUE TO URBAN FLOODING – CASE STUDY FREDRIKSTAD, NORWAY

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Abstract: During the last decades an increase in extreme rainfall has led to more urban flooding. This study is based on insurance claims of damages caused by heavy rain during 2006−2012 in Fredrikstad, Norway. Data are analysed using Principal Component Analysis. The purpose has been to find characteristics of extreme rainfall and its influence on the extent of urban flooding. The number of claims seems to be peaked in the late summer period. Furthermore, the precipitation depth the week before an extreme rainfall seems to have significantly influence for the pay out from insurers, and thus the changing in runoff factor due to soil wetness is of importance. Compared to 25-year frequency rainfall with 30 min duration, relatively less intensive, but more stable and long-lasting rain seems to lead to more claims. Experiences from previous events may help to determine the level of flood risk when extreme rainfall is forecasted.

Keywords: Insurance claims, flood prevention, Principal Component Analysis

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INTRODUCTION

It is predicted that some of the consequences of climatic change (CC) will be an increase of extreme weather events with larger and more frequent flooding in urban areas. Several studies (e.g. Semadeni-Davies *et al*., 2008a; Tait *et al*., 2008; Willems, 2012) also shows that population growth and increased wealth, in addition to CC, will have major impact on urban flooding

Extreme precipitation and flooding in cities have large social costs such as traffic disruptions, damage to infrastructure and buildings, people experiencing uncertainty for new floods, sick leave due to infectious water, lost sales for businesses, pollution of drinking water and local recipients (Lindholm *et al*., 2008). The insurance company in Norway is of the opinion that these costs could increase by 40% or more over the next ten years (Nyeggen, 2007). Decisions about prioritizing flood preventive and/or mitigating measures in drainage systems are complex. Expertise, time, economy, traffic and development of other infrastructure need to be coordinated. Professionals often experience pressure from governments, local media, developers, local politicians and citizens in general. Given this complexity, it is often easy to lose the holistic perspective needed to take good decisions for efficient solutions.

In Europe, the municipalities often own the sewer systems. Most of the sewer systems in cities were designed and built several decades ago. Before the 1960s, the main technical solution was to collect storm water and sewage from households in one large sewer pipe (combined system). The normal lifetime for these systems are typically being a hundred years or more, accordingly downtown areas in most European cities will have a large ratio of combined systems also in the future. The standard method since the late 1960s has been two-piped systems (separate system), one for sewerage and another for storm water. Increased rainfall will be a new challenge for the transportation system in addition to increased maintenance and malfunctions caused by aging (Carrico *et al*., 2012). In average, 0.44% of Norwegian sewers by pipe length are renewed every year (Lindholm, 2014). At this rate, it will take more than 200 years for a complete renewal of the systems. With a realistic lifespan of 80 to100 years for existing sewers (MEF, 2011) it is obvious that this offers challenges.

For more than 150 years, the dominating concept for urban drainage has been piped network. In recent years, focus has turned from piped networks, to a variety of solutions for storm water drainage including open trenches, ponds and streams etc. This concept has been named SUDS (Sustainable Urban Drainage System) and is considered as a necessary step towards more sustainable solutions to reduce the expected increase in urban runoff (Kennedy & Lewis, 2007; Semadeni-Davies *et al*., 2008b). New concepts of urban drainage management are different from the traditional engineering approach and force cross-disciplinary cooperation (Willems, 2012). The study presented in this paper is based on information from several disciplines; insurance, meteorology and wastewater management, and might be regarded as an example of this new approach.

In this study a comparison is made of registered rainfall and insurance claims in Fredrikstad for the period 2006–2012. The hypothesis is that some characteristics of the fluctuations in short and long term rainfall affect the extent of flooding. If such patterns are known, this can provide great socio-economic benefits, because information regarding where and when to act can be based on forecasted rain events. Events with most rainfall during this period represent the sample in this analysis. Each event is then characterized by several variables related to rainfall and damage. In this study, this sample is used in a multivariate explorative analysis. The results are further utilized to assess connections between rainfall and insurance damage.

ABOUT THE CASE SITE: FREDRIKSTAD

Fredrikstad has 76 932 inhabitants (2013). In recent years, the region has experienced several flood events caused by heavy rainfall. In the early 2000s several insurance companies held the different municipalities responsible for the damages due to limited capacity in the sewers and demanded recourse for their pay outs (Lindholm *et al.,* 2006). The demand was NOK 14.5 million for damage to 300 houses associated with one rainfall event in September 2002.

However, the insurance companies lost the court case versus the municipality since the precipitation was of such an extreme magnitude that it was regarded as a natural peril. A similar trial regarding the rain events 2006−2008 ended in a settlement between the two parties. Fredrikstad is one of the cities in Norway that has been most affected by urban flooding. In 2007 a general plan for storm water management was launched. An intention of the plan was to create awareness among developers regarding sustainable storm water solutions (Fredrikstad Municipality, 2007). Given this objective and the high number of damages in recent years, Fredrikstad is a particularly interesting case for analysing data of damages caused by urban floods.

MATERIALS

Insurance data

Insurance companies are among those that most rapidly experience the consequences of climate change. For water-related damages in Norway between 2008–2011, only 4% of the payments were defined as natural hazards (Ebeltoft, 2012). A national insurance pool called Norwegian Natural Perils Pool covers such damages. However, each individual insurance company must initially cover most claims that are caused by that limited capacity of the sewer system.

When a building is flooded, the insurance company is

Table 1. Type of damages and the codes most relevant to flooding

Installation		Source		Cause	
Code	Description	Code	Description	Code	Description
G	Outdoor – water- and sewer system	I	precipitation/snow melt/ground water	9	missing value
H	Water penetration from outside through foundation			E	old age
I	Water penetration from outside above foundation			G	Stop in sewer / sewer back up
				I	Influence from outside
				J	Drainage system

contacted by the owner. An appraiser is sent by the insurance company to assess the damage. The report from the appraiser constitutes the basis for the economic compensation. Details regarding the damage are recorded and stored in a national database, which is administered by Finance Norway, which is the industry organization for the Norwegian finance and insurance companies. Free web-access is provided to an excerpt of this data, collected in a national database named VASK (Finance Norway, 2013).

There has been several court cases in recent years, were insurance companies has claimed that municipalities has not fulfilled their responsibility regarding flood preventions. The court decisions do not provide a clear answer. According to The Ministry of Climate and Environment there is still need for clarifying the responsibility of the municipalities and the responsibility of the individuals, during extreme weather events (Miljøverndepartementet, 2010). Due to the increased number of flood related claims the past few years, insurance companies state that they will hold the municipalities even more responsible for such damages in the future (Nyeggen, 2007).

Municipalities do not have regularly access to Finance Norway's database for flood events on a detailed level. Hence, they have been forced to make their own records to get an overview of the situation. Information is obtained by own investigations, random contact with residents or from recourse cases. This information has thus become very important when prioritizing flood preventive measures. However, these registrations are believed to be incomplete because detailed information from the insurance companies is missing. As a part of Finance Norway's dedication to prevent climate-related damages (or any damage that lead to a claim), their database has been made available for specific research purposes.

The data from the insurance companies includes useful information linked to each incident that has led to a claim. The main information in this study has proved to be:

(a) Date of damage
(b) Compensation sum
(c) Type of installation
(d) Source of the damage (e.g. precipitation)
(e) Cause of the damage (e.g. aging)

It is assumed that damages and flooding occur on days where heavy rainfall is recorded. Furthermore, proportionality is expected in that dates with the highest total compensation sum simultaneously have been days with most rainfall. The code system for classifying the damage is further discussed in the section below. From days affected by flooding it was possible to derive a number of numerical variables that was used in the analysis.

Code system of insurance data

The appraisers from most of the insurance companies in Norway are required to code each water related claim as a part of their report describing the actual damage and the related costs. This national reporting system was standardized in 2006, and the market share for the insurance companies using the system in Norway is approximately 90%. In the report, all data concerning the damage should be coded in three categories (Finance Norway 2015):

(a) Installation: This is a rough description of location where the damage has occurred, e.g. water or sewer pipe, inside or outside the building.
(b) Source: This is a more detailed description of the site or the damage itself. There is a separate code that covers precipitation damages, which is used directly in this study.
(c) Cause: This code describes the actual cause for the damage. It might be old age, frost, stop in sewers etc.

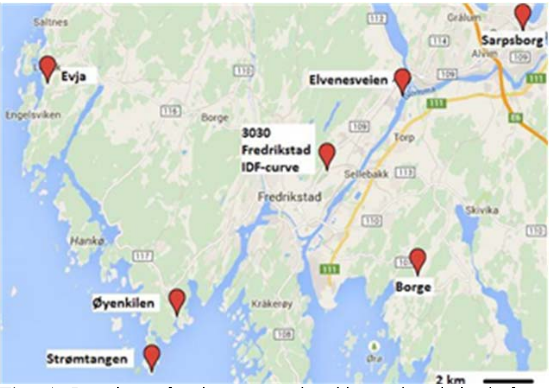

Fig. 1 Location of rain gauges in this study, derived from Meteorologisk institutt (2015).

Precipitation data

Only a few Norwegian cities have more densely distribution of rain gauges than Fredrikstad (Nielsen, 2013). In this analysis, precipitation data is collected from several gauges distributed throughout the district.

Two weather stations in this study, Strømtangen and Sarpsborg, is part of the national meteorological network run by The Norwegian Meteorological Institute (Meteorologisk institutt, 2015), and are included in the analysis for seasonal precipitation. Even though they are at the edges of the case area, they are considered to be relevant due to their continuous recordings of precipitation from all days during 2006–2012.

From 1970−1995, a weather station located in the Centre of the city (3030 Fredrikstad) recorded precipitation. These records defined the basis for the Intensity-Duration- Frequency Curve (IDF-Curve) which is still in use when the purpose is to determine extreme rainfall that statistically can occur in this area.

Furthermore in this study, data from four local rain gauges, Øyenkilen, Evja, Elvenesveien and Borge, owned and operated by Fredrikstad municipality are used. The rain gauges are distributed all around the region as can be seen from **Fig. 1**. The instruments are all Lambrecht 1518 H3, so-called tipping-bucket rain gauges with time resolution of 1 minute. The bucket record each 1 mm rainfall that is further automatically transmitted to a computer server and frequently transmitted to the Norwegian Meteorological Institute (Meteorologisk institutt, 2015). A limitation is that discontinuity in the series of measurement from local rain gauges has occurred, especially in 2006−2007. If a value has been considered as uncertain, the validity has been cross-checked with current recordings from other rain gauges. In some cases values are excluded from the sample.

The software used in this study will then fill missed values estimated from the non-missing data (CAMO, 2006). An experience from this study which should be paid more attention is the importance of getting continuous observation from outdoor gauges during changing weather conditions. Anyway the data series in this study are considered as representative for the events analyzed in this study.

METHOD

The hazard – a part of the risk triangle

The risk for flooding in urban areas can be viewed in many ways and calculated by different methods. As a basis for this study the Risk triangle described by Crichton (1999) and viewed in **Fig. 2** is used.

This triangle illustrates an interaction between the three elements hazard, exposure and vulnerability. These elements can all be considered as integrated part of risk management to flooding. **Figure 2** is also widely adopted and used in public reports related to CC and more specific articles in urban flooding (e.g. IPCC, 2012; Kaźmierczak and Cavan, 2011; Lindley *et al*., 2006).

If the area of the triangle represents the risk-level, metaphorically the risk can be reduced if the length of one or more of the sides of the triangle is shortened. In relation to risk-reduction, this study only deals with the "hazard-side" of the triangle in **Fig. 2**.

In this context, hazard reflects the frequency and severity rain storms causing flood in urban areas. Flood is often caused by short duration intense rainfall which occurs locally, and this type of rain is often difficult to forecast, warn against and prepare for (Kaźmierczak and Cavan, 2011). As mentioned, CC-predictions indicate an increasing trend of the hazard. For the local society there are limited possibilities to control this, except to providing adequate drainage, pursuing a sustainable flood management practice and maintain a good preparedness (Crichton, 2012).

Both exposure and vulnerability are considered to play an important role as an integrated part for risk reduction at a local level. Exposure describe to which extent the urban communities are located so that they are more or less exposed to flooding. Vulnerability is seen as the individuals' ability to handle floods.

Fig. 2 The risk triangle (Crichton, 1999).

Principle Component Analysis

The data extracted from the database of the insurance companies are related to the corresponding meteorological data for Fredrikstad and analysed using the method of Principal Component Analysis (PCA). From PCA it is possible to reduce the dimensionality of the dataset, from many variables to fewer latent variables. The latent variables are interpreted in accordance to the original variables in the original data- which reflects new components (principal components) best.

The information carried out by the original variables, is projected onto a smaller number of underlying latent variables, called principal components (PC). The first principal component accounts for the maximum proportion of variance from the original dataset. The remaining variance is described by PC-2, PC-3 etc. which are perpendicular to each other. All principal components will then form a new orthogonal coordinate system that best describes the total variance of the dataset in each principal direction. The explorative analysis process is done by graphic analysis of the PCs and other relations. It is possible to view underlying structures in the data not observed with a univariate tool (Esbensen *et al*., 2000; Kaźmierczak and Cavan, 2011).

The score plot shows the distribution of samples, and patterns, groupings and similarities among the objects can be viewed. The loading plot reflects the importance for each variable due to the principal components. The score plot and loading plot are interrelated. If sample X is plotted to the far right in the score plot, this sample usually has high value of variable Y, if Y is placed to the far right in the loading plot.

The software Unscrambler® version 10.3 is used for the further PCA-analysis (Camo, 2015). Finally the dataset which is used in this analysis consists of different dates, corresponding compensation sum and recorded precipitation at different rain gauges.

Table 2. Correlation between monthly distributions of claims and registered source = I (S_I) and codes for installation (I_X)

Codes for installation (see table 1)	G	H	I
No. of damages 2006-2012	115	736	495
Corr [S_I,I_x]	**0,995**	**0,973**	**0,965**

Table 3. Correlation between monthly distributions of claims and registered source = I (S_I) and codes for causes (C_X)

Codes for cause (see table 1)	9	E	G	I	J
No. of damages 2006-2012	14	125	232	700	275
Corr [S_I,C_x]	0,290	0,542	0,981	0,998	0,932

EXTRACTION OF DATA FOR THIS ANALYSIS

Identification of relevant insurance registration codes for flood damages

The use and combination of insurance registration codes referred to in this article, has been evaluated by municipal professionals in several Norwegian cities (Vestlandsforskning, 2015). Their main objective of that study was to evaluate the system of coding the type of damages etc. The conclusion was that it is beneficial for municipalities to get access to damage data from insurance companies and this will improve their efforts to prevent water related damages at a local level.

Flooding of a building may have multiple causes and the use of classification codes depends on how they are subjectively ranked. The aim of this analysis is not to point out the responsible part, rather to view this as a multidisciplinary challenge for the community. In this context, the current code system is found to be reasonable.

A flood can theoretically occur in any month of the year. One possible method to detect errors in code-use, is to look at the monthly distribution of damages in relation to source = I (precipitation). If there is a fair correlation between the monthly distribution of these damages and the use of codes for installation and cause related to the type of damage, it is reasonable to assume that the combination of codes is logical and not randomly written down. The calculated correlation coefficients for monthly distribution of claims and source are shown in **Tables 2–3**.

Most of the registered codes in tables 3 and 4 indicate a strong correlation with monthly distribution of claims due to precipitation. The correlation coefficient indicates uncertainties regarding whether claims coded by 9 or E as the cause really are consequences of heavy rain. These claims seem to occur more regularly throughout the year, and have not the temporal fluctuations observed by the other rainfall related claims. This might be a result of miscoding, and these claims are therefore excluded from the sample.

Selection of dataset for analysis

The dataset consist of an extraction of correlated dates and variables related to recorded rainfall and compensation sum the current day. To get a representative dataset it is of major importance to select dates with most claims and/or heavy rain. In all analysis claims coded with G, H and I for installation, I for source and G, I, and J for cause as described in table 2 and 3 are included.

In the first analysis for seasonal precipitation, all flooding events during 2006−2012 are included. For the two remaining analysis some selected dates with heavy rainfall and claims with codes as described above are used. For selection of the sample, some criteria are defined:

(a) Events which occurred during 1 November and 31 March is excluded from the sample. Unlike rain, recorded snowfall will not give the immediate response to flooding. By excluding seasons where snowfall may occur, uncertainties with respect to the type of precipitation will be eliminated. As we will see later, there were hardly any flooding events this time period in Fredrikstad.

(b) Only days with ≥ 4 claims were included. Ensuring that selected dates have affected a minimum number of people with some spatial distribution.

(c) If at least three gauges on average recorded more than 25 mm within 24 hours, the dates were included in the dataset. According to Mamen *et al.* (2011) approximately 40 mm rainfall during a 24 hour period represent a 2-year frequency in Fredrikstad, but this 24-hour-limit was only exceeded seven times during 2006−2012.

(d) A single rain gauge which exceeded 2 years-frequency for short-time duration (30, 60, 120 or 360 min) when at least two other rain gauges had recorded rain, was included in the sample set. With this criterion short-duration heavy rain, but less than 25 mm per day were included in the data set too.

From the two last criteria, also days with no claims at all will be included. This was of particular interest, because rainy days with no claims might occur, even though the recorded rainfall was similar to days with flooding. Five days was excluded from the data set though they had more than four claims.

Three of these days had no recorded rain, but were adjacent to days with major damages indicating that these claims were incorrectly dated, probably because the flood occurred late evening or early night. On two other days some claims were registered, but no rain. It is possible that the rain gauges were out of service. If no rainfall was recorded, a flooding situation was unlikely and the flood damages give no sense. Based on the criteria above, the number of samples (dates) used for further analysis are shown in **Table 4**.

Table 4. Number of samples (dates) in the analysis of events

No. of days acc. to "claim-criterion" above	15
No. of days acc. to "rainfall-criterion" above	24
Days covering both criteria	7
Samples (sum of dates)	32

RESULTS AND DISCUSSION

Three different analyses were carried out. Even though there were some differences in the samples, the purpose and the basis for the data are all the same. All events took place between 2006 and 2012 in Fredrikstad. The total number of selected claims during this time period is n=1076 with a total compensation sum of 56.6 mill NOK.

The diagram in **Fig. 3** was used to interpret seasonal fluctuations in precipitation and claims. The plot in **Figs 4a–b** shows how the daily and weekly amount of rain derived from dates selected in table 3 will affect the damage cost. Finally in **Fig. 6** the intensity of the recorded rainfall from 30 to 720 min is assessed in relation to both cost and frequency from 30-year-normal.

Analysis of seasonal precipitation in relation to urban flooding

To locate any patterns in the seasonal distribution, the compensation sum of the claims and rainfalls were plotted, according to the monthly distributing during 2006−2012. For x (precipitation or claims) the relative rate Y_m for each month (m) and each monthly sum $x_{m,y}$ for the years (y) 2006−2012 were calculated using formula 1 and plotted in **Fig. 3**. **Equation 1** is the monthly relative rate Y_m (claims or precipitation). Precipitation was derived from five different time series. Referring to the limitation of the local rain gauges during winter, the recordings from the two weather stations Strømtangen and Sarpsborg are shown in the period 2006−2012. In addition to that a 30-years-normal-curve from the city centre of Fredrikstad 1970−95) exists.

$$Y_m = \frac{\Sigma_y(x_{m,y})}{\Sigma_m \Sigma_y (x_{m,y})} \times 100\% \qquad (1)$$

In July, August and September the compensation sum from flooding has a distinct peak. 79% of the compensation for flooding in Fredrikstad during 2006−2012 occurred in these months. However in October the monthly rainfall normally has a peak. Indeed there were some major events these years e.g. 14 August 2008 (218 claims) and 11 September 2011 (117 claims), and during these months the probability for flooding seem to have a significant increase. Winter related flooding such as snowmelt or rain on frozen ground, seem to have almost no impact.

The data from Strømtangen clearly exhibits a peak in August. However for August the years 2010 and 2012 that was most rainy, while hardly any claims were recorded. Accordingly there is no clear correlation between the rainfall peak and the damages that occurred in August 2006−2012.

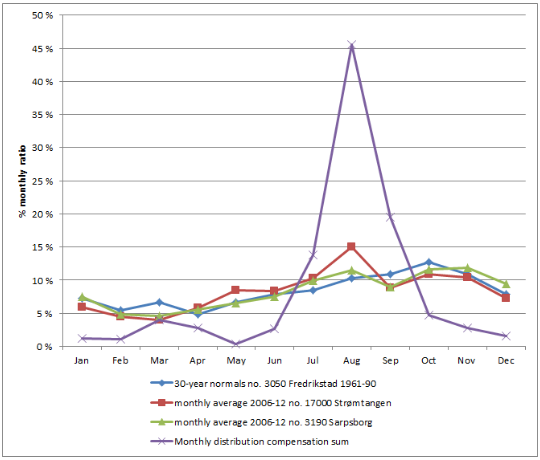

Fig. 3. Monthly distribution of precipitation and claims in Fredrikstad 2006−2012

In south-eastern Norway, the rainfall typically falls in to two main groups: Convective and Stratiform. According to Ødemark (2012) the Stratiform rainfall can dominate all over the year while convective precipitation dominates in the warm season. Thus in the late summer there is a risk of flooding that may occur as a result of rain from both precipitation types, and this may be an explanation for the increased flooding events during this season. Halvorsen (1942) observed that the south- eastern part of Norway received greater amounts of Stratiform rainfall when south-westerly winds blows over the region. This phenomenon has not been confirmed in this study. Although this study is from a limited time-period, the late summer rain in this part of Norway is a well-known phenomenon (Fredrikstad municipality, 2007). The distinct peak of damage cost clearly shows the increased risk for flooding in July, August and September.

Multivariate analysis of daily and weekly precipitation in relation to urban flooding

Long-time rainfall, saturated ground and water courses with a high water level, may affect the risk of flooding. In this section possible correlation between the number of claims and the rainfall the current day, the preceding day and the preceding week (7 days) are investigated.

Measured precipitation from four of the local rain gauges on the particular date, the day before and the accumulated values for the week ahead gave 12 different variables. In Fig. 4a each variable are named "Day", "Day bef" or "Week bef", respectively in addition to the first letter of the rain gauges location. Plot in **Fig. 4b** refers to the group of compensation as mentioned above and characterizes a rainfall event from expensive to no claims at all. In the loading plot the different variables are labelled. As category variables in the score plot the total sum of compensation are divided into four groups. For "Expensive dates" (named "exp" in the plot) the total compensation sum for Fredrikstad exceeding 1 mill NOK. Dates marked as "medium" in the plot are in the interval from approximately 400 000 to 1 000 000 NOK and "little" are below 400 000 NOK. As mentioned above, some dates are chosen due to high recorded precipitation and no pay-outs at all. In the score plot they are labelled "no". PC-1 and PC-2 are 48% and 20%, respectively, which means that 68% of the variance in the dataset is described by the model.

The correlation loading plot is computed for each of the variables in the plot. The correlation loading, is the correlation between the scores (from the PCA) and the actual observed data. Correlation loadings are computed for each variable for the displayed latent variables (PCs or factors). The 2-D plot contains two ellipses that indicate how much variance is taken into account by the model. The outer ellipse is the unit circle and indicates 100% explained variance, while the inner ellipse indicates only 50% (Camo, 2015). The daily precipitation of Elvenesveien ("Day-Elv") and Evja ("Day Evj") are within the inner ellipse which means that this variable are more poorly described in the model and seem to be of less importance than the other variables.

From the loading plot PC-1 clearly describes the amount of precipitation the week and the day before the events. Values from all variables are clustered at the far right along the axis. The PC-2 shows the daily precipitation from different variables. The variables describing rainfall during one week from the different rain gauges are more clustered than those showing daily precipitation. It seems that the relative differences between the measurements are less for weekly rainfall than rainfall pr. days. In the score plot each sample is labelled and coloured uniquely from expensive ("exp") to "no" claims according to the predefined groups. Dates with no claims are clustered at the left side of the score plot, while the most of the expensive dates seem to have higher value of PC-1 and PC-2. It is reasonable that the two samples at the upper part of the score-plot (highest PC-2 value) both were days with high precipitation and a large number of floods. The clusters along the PC-1 axis indicate the importance of the rainfall the day and week before a flooding occurs. The red marks at the lower left side of the score plot are dates were only one rain gauge recorded heavy rain.

Days with no flooding are negatively correlated with the rainfall the prior day and week; this indicates that the nature of the surface is greatly affecting the run-off coefficient. It may not be entirely surprising that variables related to rainfall the prior day and week before an event is correlated. Since the first variable is included in the second, the fluctuations will not be independent. The third principal component (PC-3) describes 13% of the variance. This component seems to describe the day and week rainfall.

From previous studies, among others Holý *et al.* (2013) and Sarikelle (1980), it is showed that the run-off coefficient will increase during the first minutes of a

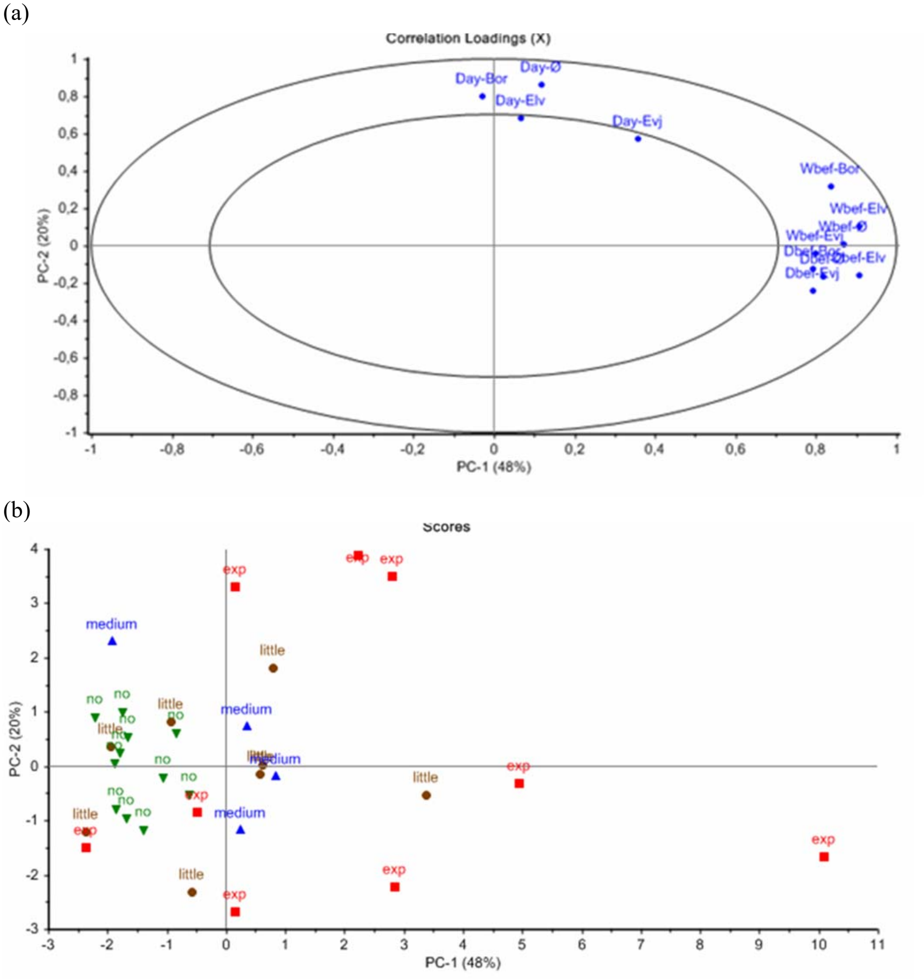

Fig. 4 (a) PCA-loading-plot - Daily and weekly precipitation and water-related claims for selected events, and (b) PCA - score plot - Daily and weekly precipitation and water-related claims for selected events.

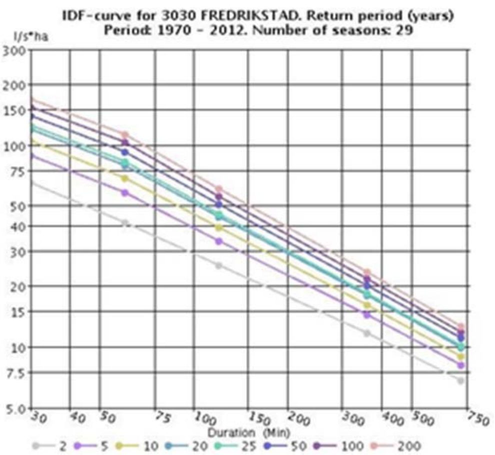

Fig. 5. IDF-curve, station no. 3030 Fredrikstad (Meteorologisk Institutt, 2015)

short-time rainfall independent of type of soil. A study from the US, (Horner *et al*., 2004), stated that the runoff also differs greatly within season and year depending on prior amount of rain. A study of 24 hours precipitation events in a semi-urban area in China (Shi *et al*., 2007) states, that on average runoff under wet soil conditions are two times higher compared to dry soil conditions. Another study in an urban catchment in Baltimore U.S (Brun and Band, 2000) showed that there is a relationship between runoff factor on one hand and the soil saturation and impervious area on the other. The most dramatic increase in runoff ratio for any given percent soil saturation occurs when the fraction of impervious area covers between 20 and 80%. Finally, a study from Germany (Niehoff *et al*., 2002) confirms the impact of the soil moisture conditions and land-use in relation to storm run-off. The fact that **Fig. 4a–b** seems to indicate reduced risk for flooding from rainfall if it occurs after a period with little rain in advance, confirm the findings in these studies.

Multivariate analysis of intensity compared with IDF-curves Fredrikstad

An Intensity-Duration-Frequency curve (IDF-curve) shows the probability that average rainfall intensity will occur in a specific region. The calculated probability is based on statistical analysis of recorded rainfall data over a long period, typically 30 years. This curve is required when designing drainage systems.

The purpose of the study presented in this section, is to locate patterns in the short-time duration rainfall and its impact of flooding. The measured progress of rain is characterized as either the long lasting / less intensive or short term/intensive rain, depending on the IDF-curve is intersected from above or below. Furthermore, it is interesting to investigate whether this characteristic is significantly influencing the compensation sum to flooded residents.

IDF-curve (Intensity-Duration-Frequency) for central Fredrikstad (3030 Fredrikstad) has been included in this analysis. The curves shown in Fig. 5 are obtained from the database eklima.no run by the Norwegian Meteorological Institute (Meteorologisk institutt, 2015).

Each plot in the graph illustrates the duration of an extreme rainfall and the corresponding intensity of that rain, derived from observations through several years. The adjacent coloured lines in the IDF-diagram, represents different frequencies, and the lowermost line indicates a rainfall occurring every 2 years (with a probability of 0.5 per year). The lines above this represent even worse but less frequent storms (return period 5 year, 10 year etc.).The data for this analysis are selected using the same criteria as in the section above. In the prior PCA- analysis daily and weekly rainfall were highlighted, and each date consisted a sample defined by multiple rain gauges. Short duration rainfall may occur locally and may not be recorded all over the area. In this analysis a sample consist of recordings from each rain gauge on the selected day. Thus, in this study there will be 125 objects including IDF-values from different frequencies.

There are five variables in this plot, maximum recorded rainfall 30, 60, 120, 360 and 720 minutes, respectively. From **Fig. 6** it is shown that the two first principal components describe almost all variance in the dataset. As seen from the IDF-curve the intensity is inversely proportional with duration for all values. This will obviously make a higher correlation among the data compared to e.g. the data shown in **Fig. 4a–b.**

The loading plot is not shown, but views that all variables are well described by PC-1. When plotting PC-1 and PC-2, the variables for the shortest duration rainfall (30 and 60 min) are slightly below the PC-1 axis (negative PC-2 value). Durations more than 120 min are plotted above the PC-1 axis.

The farther to the right in Fig. 6 the more rainfall is recorded, and PC-1 then describes the extremity of a rainfall. Relative weight to long lasting intensity (more than 120 min) brings the plot to the upper part of the PC-2 axis and vice versa. This can be explained as that negative values of PC-2 indicates short-time torrential rain. If this sample had been plotted in Fig. 5, the slope would have been steeper than the frequency curves.

If a recorded time series had coincided with the frequency of e.g. 5 year-rain in the IDF-curve, the object would have been plotted near the grey marked point "IDF-5" in the score plot. As defined in the previous section Expensive, medium, little and days with no compensation are marked with initial letters and different colours in the score plot.

For objects at the left side of the score plot, little rainfall is recorded. Since the colour code in the plot is making no reference to the spatial distribution of the damages, some red-marked objects are at the far left side of the score plot. This probably means that another part of the region was more affected that particular day.

The more intensive rainfall, the further to the right side of the score plot. As expected, the plots furthest to the right, resulted in higher compensation sums for flood damages. Most of the objects in the score plot are placed above the PC-1 in 1st and 2nd quadrant, and the most expensive dates tend to turn upwards to the right corner in the score plot. This means that the rain intensity has been long lasting relative to the IDF- values. The plot to the far right in the score plot is the time-series for Øyenkilen 14 August 2008 which was the most extreme rainfall event recorded in the district during 2006−2012. This rain had a 30 minute-intensity as a 25-year frequency rain, but the intensity remained relatively high and exceeded a 200-year frequency rain after 120 min.

Except for a few records near the origin, there are only two objects which are located in the 4th quadrant and below the IDF-points. This suggests that both these rainfall started intensively, but declined relatively fast. It is assumed that these rainfalls had little spatial distribution. The plot at the bottom right of the figure was an extreme rainfall event recorded at Elvenesveien 10 July 2012. It began as a 25-year frequency rain after 30 min, but declined soon and had in average a 5-year frequency rain after 720 min. This observation is confirmed by looking at the addresses for the claims; all nine damages that day in Fredrikstad were located near this station.

When designing drainage systems, more attention should be paid to the rainfall over a larger area rather than recordings from one single point. The IDF-curves in Fig. 5 was derived from years with several rainfalls, but only from one single point (only one gauge). The area precipitation tends to be less than point precipitation (e.g. Nielsen, 2013; Willems, 2012). If similar precipitation is recorded from several gauges, the spatial distribution of a

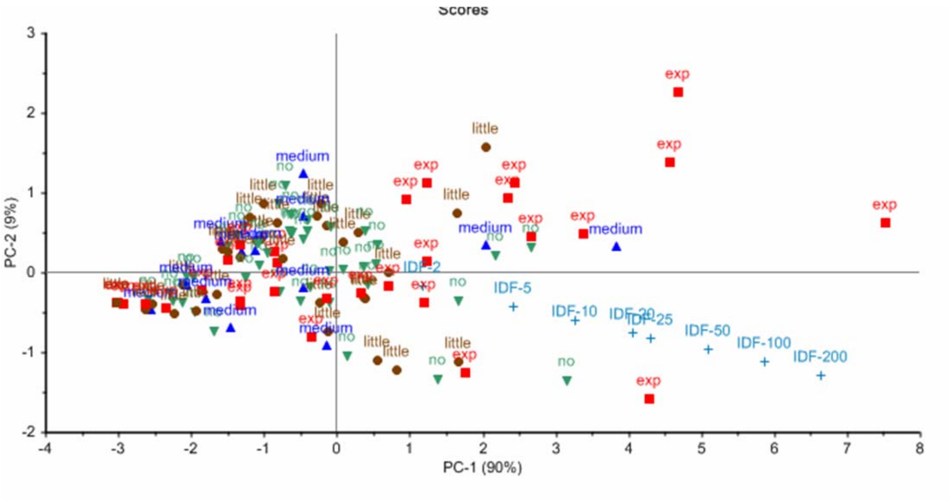

Fig. 6 PCA-score plot - Short time duration rainfall (from 30-720 minutes) at selected dates in relation to claims

rainfall is considered to be better described. IDF-curves for the catchment will appear lower and flatter than IDF-curves derived from one single point (Sivapalan and Blöschl, 1998). This is confirmed by the plot in Fig. 6, and the most extreme recordings would have crossed the IDF-curve from below, since their intensity curves seem to be flatter.

From **Fig. 6**, most of the days with high sums of compensation, the rain starts with relatively low intensity, but the intensity remains higher over longer time relative to the observations included for calculation of IDF-curves. Thus very extreme short duration rainfall with little spatial distribution within a small area of Fredrikstad, do not seem to be the main reason for the claims during 2006–2012.

CONCLUSION

The results from these analyses indicate a correlation between rainfall and the extent of urban flooding in terms of water-related insurance claims.

Regarding the hazard at a local level, obviously the point in time to set an increased emergency situation for flooding is crucial. Specific operation and maintenance measures should be focused when a hazard is forecasted and within seasons with increased probability for flooding. Good preparedness will obviously reduce the risk when a critical situation arises.

Monthly distribution of precipitation and claims in Fredrikstad 2006–2012 shows a distinct peak of damage cost, only a few months a year. This clearly indicates that the emergency measures for flooding in the late summer should be highlighted, while this focus can be lower in other seasons. Limited capacity of the piped drainage and sewer system plays an important role for the damage rates. Natural flood management practices should emphasize the cleaning of drains and ensure adequate drainage paths on the surface. Maintenance of these systems will be more important in certain seasons.

PCA-plot of daily and weekly precipitation of the selected dates in relation to claims indicates a pattern between previous rainfall and increased risk for flooding. Little precipitation the week before is a plausible explanation for why some days with heavy rain results in no claims. Although sealed areas dominate in the urban environment, the risk of flooding is reduced when ground is dry and unsaturated. Thus the runoff factor is an important parameter which should be paid considerable attention when considering a potential emergency situation. Forecasted heavy rain after a wet period should therefore lead to a higher level of emergency for flooding.

The PCA-plot of short time duration rainfall confirms that the most expensive events occur during the most intensive rainfall. The PCA-plot indicates that the most extreme floods during this period were caused by hours of intensive rain, rather than shorter torrential rain.

When utilizing IDF-curves for dimensioning drainage pipes, a CC-factor is often added to take possible future extreme events into account. During 2006−2012 several recordings of rainfall in Fredrikstad had an intensity exceeding the 200 years-frequency limit. The local authorities require using rainfall with a 25-years frequency as input when dimensioning storm sewers (Fredrikstad municipality, 2007). The extent of the largest floods it is not only a matter of undersized pipes. The most extensive rainfall and floods during this period occurred in August 2008 where average rainfall within 60 min at Øyenkilen was recorded to 105 l/s pr. ha. This corresponds to a rain with a frequency between 100 and 200 years from the IDF-curve. However, if the pipes are designed for a 25-year rainfall with 30 min duration, it should be able to tackle an intensity of 124 l/s pr. ha. This illustrate that as in addition to sufficient pipe-dimension, a well-maintained drain system which ensures a rapid run off is of great importance as flood prevention measure.

Scenarios for Norway indicate a future increase in annual precipitation of 0.3−2.7% per decade up to 2050 (Agersten, 2002). As described above there are limited possibilities at a local level to deal with the extent of the hazard. This study has identified some relationships between the characteristics of the precipitation and the number of insurance claims. If some of these patterns pointed at in this study are taken into account, the risk for urban flooding may be reduced.

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REFERENCES

Agersten, S. (2002) *Analysis of extreme daily precipitation and return periods in Norway and NORDKLIM area: Norwegian*. Meterological Institute.

Brun, S. E. and Band, L. E. (2000) Simulating runoff behavior in an urbanizing watershed. *Comp. Environ. Urban Sys.,* **24**(1), 5-22.

CAMO (2006) *The Unscrambler User Manual*: www.camo.com. Camo. (2015) The Unscrambler® Interpreting PCA plots". City.

Carrico, N., Covas, D. I. C., Almeida, M. C., Leitão, J. P. and Alegre, H. (2012) Prioritization of rehabilitation interventions for urban water assets using multiple criteria decision-aid methods." Water Science and Technology, 66(5), 1007-1014.

Crichton, D. (1999) *The Risk Triangle*.

Crichton, D. (2012) *Flood plain speaking*. T. C. I. Institute, (ed.) City.

Ebeltoft, M. *Klimaendringer gir oss nye utfordringer som krever nye løsninger - Bruk av forsikringsdata i forebyggende arbeid*. Presented at Meeting 6. desember, Oslo.

Esbensen, K. H., Guyot, D. and Westad, F. (2000) Multivariate data analysis - in practice: an introduction to multivariate data analysis and experimental design, Oslo: Camo.

Finance Norway. (2013) VASK- vannskaderegisteret (National Register of Water Damages)", F. Norway, (ed.) City.

Finance Norway. (2015) Forklaring til kodene i VASK (Explaining the codes in VASK - National Register of Water Damages)", F. Norway, (ed.) City.

Fredrikstad Municipality (2007) Overvannsrammeplan (Master plan for Drainage and Storm water).

Halvorsen, I. (1942) On the distribution of precipitation over South-Eastern Norway when fronts pass from the west and from the south-west." Meterological Annuals, Norwegian Meteorological Institute no. 11.

Holý, M., Biswas, A.K. and Biswas, M.R. (2013) Erosion and Environment: Environmental Sciences and Applications: Elsevier Science.

Horner, Heungkook and Burges. (2004) *Hydrological monitoring of the Seattle Ultra-Urban Stormwater management projects.* Summary of the 2000-2003 Water Years

IPCC (2012) *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change.

Kaźmierczak, A. and Cavan, G. (2011) Surface water flooding risk to urban communities: Analysis of vulnerability, hazard and exposure. *Lands. Urban Plann.,* **103**(2), 185-197.

Kennedy, A. & Lewis, D. (2007) Attaining the most sustainable solution in stormwater control in England and Wales. LESAM 2007. *Proc. of City: 2nd Leading Edge Conference on Strategic Asset Management*, Lisbon, Portugal October 17-19, 2007.

Lindholm, O. (2014) Fornyelse av VA-nettet i 2013 (renewing water and wastewater system in Norway 2013). *Vann*, 4, 537-540.

Lindholm, O., Endresen, S., Thorolfsson, S., Sægrov, S., Jakobsen, G. and L., A. (2008) *Veiledning i klimatilpasset overvannshåndtering*, Hamar, Norway: Norsk Vann BA.

Lindholm, O., Schilling, W. and Crichton, D. (2006) Urban Water Management before the Court: Flooding in Fredrikstad, Norway. *J. Water Law,* **17**(5), 204-209.

Lindley, S. J., Handley, J. F., Theuray, N., Peet, E. and McEvoy, D. (2006) Adaptation Strategies for Climate Change in the Urban Environment: Assessing Climate Change Related Risk in UK Urban Areas." Journal of Risk Research, 9(5), 543-568.

Mamen, J., Benestad, R. and Haugen, J.E. (2011) Analysis of short term precipitation in Norway 1967-2010

MEF (2011) Vann og avløp i Norge: Tilstand og tiltak (Water- and wastewater in Norway State of the art).

Meteorologisk Institutt (2015) *Eklima*. N. M. Institute, (ed.) City: www.eklima.no.

Miljøverndepartementet (2010) *Tilpassing til eit klima i endring NOU* 2010:10 (Adaption to a changing climate). City: https://www.regjeringen.no/nb/dokumenter/nou-2010-10/id624355/ [accessed 11 June 2015].

Niehoff, D., Fritsch, U. and Bronstert, A. (2002) Land-use impacts on storm-runoff generation: scenarios of land-use change and simulation of hydrological response in a meso-scale catchment in SW-Germany. *J. Hydrol.,* **267**(1–2), 80-93.

Nielsen, T.R. (2013) *Analysis of the importance of area precipitation*, NTNU, Norway. Nyeggen, E., Gjensidige Forsikring. (2007) Klimaendringene – nye utfordringer for forsikring? (Climate change - new challenges for the insurance industry?)". City.

Sarikelle, S., Chuang. Y-T. (1980) *A simplified Stormwater Quantity and Quality Model*, EPA, (ed.) Proceedings Stormwater Model (SWMM) City.

Semadeni-Davies, A., Hernebring, C., Svensson, G. and Gustafsson, L.-G. (2008a) The impacts of climate change and urbanisation on drainage in Helsingborg, Sweden: Suburban stormwater. *J. Hydrol.,* **350**(1–2), 114-125.

Semadeni-Davies, A., Hernebring, C., Svensson, G. and Gustafsson, L. G. (2008b) The impacts of climate change and urbanisation on drainage in Helsingborg, Sweden: Combined sewer system. *J. Hydrol.,* **350**(1-2), 100-113.

Shi, P.-J., Yuan, Y., Zheng, J., Wang, J.-A., Ge, Y. and Qiu, G.-Y. (2007) The effect of land use/cover change on surface runoff in Shenzhen region, China. Catena, **69**(1), 31-35.

Sivapalan, M. and Blöschl, G. (1998) Transformation of point rainfall to areal rainfall: Intensity-duration-frequency curves. *J. Hydrol.,* **204**(1–4), 150-167.

Tait, S.J., Ashley, R.M., Cashman, A., Blanksby, J. and Saul, A.J. (2008) Sewer system operation into the 21st century, study of selected responses from a UK perspective. *Urban Water J.,* **5**(1), 77-86.

Vestlandsforskning. (2015) *Pilot project on testing of damage data from the insurance branch to assess climate vulnerability and prevention of climate-related natural disaster in selected municipalitie*s.

Willems, P. (2012) Impacts of climate change on rainfall extremes and urban drainage systems, London: IWA publishing.

Ødemark, K. (2012) Extreme short term precipitation in eastern Norway from pluviometer and radar data), Oslo: Norwegian Water Resources and Energy Directorate).

Paper III

Geir Torgersen, Jan Ketil Rød, Knut Kvaal, Jarle T. Bjerkholt and Oddvar G. Lindholm (2017)
Evaluating Flood Exposure for Properties in Urban Areas Using a Multivariate Modelling Technique

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water

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Article

Evaluating Flood Exposure for Properties in Urban Areas Using a Multivariate Modelling Technique

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Abstract: Urban flooding caused by heavy rainfall is expected to increase in the future. The main purpose of this study was to investigate the variables characterizing the placement of a house, which seem to have an impact when it comes to the exposure to floods. From the same region in Norway, data from 347 addresses were derived. All addresses were either associated with insurance claims caused by flooding or were randomly selected. A multivariate statistical model, Partial Least Square Regression (PLS), was used. Among others, the analysis has shown that the upstream, sealed area is the most significant variable for characterizing properties' exposure to urban flooding. The model confirms that flooding tends to occur near old combined sewer mains and in concave curvature, and houses located in steep slopes seem to be less exposed. Using this method, it is possible to rank and quantify significant exposure variables contributing to urban floods within a region. Results from the PLS-analysis might provide important input to professionals, when planning and prioritizing measures. It can also predict flood-prone areas and make residents aware of the risks, which may induce them to implement preventive measures.

Keywords: urban flooding; exposure to floods; insurance claims; partial least square regression

1. Introduction

Urban flooding caused by extreme rainfall is exacerbated by insufficient drainage and sewer systems. This type of flooding has received less attention than other floods, due to the smaller scale of individual events [1], despite the fact that in the UK, 16,000 properties are at risk of sewer flooding in the course of a decade. In the UK, these floods, caused by short-duration events, could increase from 200,000 in the present year to 700,000–900,000 in 2080 [2]. In 2007, the insurance companies in Norway estimated that the costs of urban flooding in Norway could increase by 40% or more over the next ten years [3]. When adjusted for inflation, the overall cost for precipitation damages during 2012-2014 has proven to be 46% higher compared to 2008-2010 [4].

Numerous variables have an impact on the risk of flooding. Recent literature regards the total risk as a composition of Hazard, Vulnerability, and Exposure, and they can be used as a framework to group relevant variables [5–7]. When it comes to the frequency, intensity, and duration of rainfall, they can all characterize the weather extremes and be linked to the Hazard of floods. The level of risk also depends on the Vulnerability and Exposure, explained respectively as how to cope with the floods and the places that will potentially be affected. The total risk can decrease by focusing on the adverse impact from all kinds of variables, and in a more comprehensive model, it should be possible to add variables from any of these three groups.

Traditionally, studies regarding urban floods include dynamic, hydraulic modelling, dealing with the speed and volume of flooded water and intended to determine exposed areas. This study highlights the exposure to floods, as we use a database of addresses where flooding has occurred as a basis. In this study, we conducted a statistical analysis on GIS generated terrain variables linked to addresses. Whether a house has been flooded or not can be regarded as a response variable for a complex set of parameters. The present research was designed by using Partial Least Square regression (PLS) on two sets of addresses. The first group had experienced urban flood events during the years 2006–2012. All selected claims occurred due to rainfall and had a link to the sewer system. The second consisted of randomly selected addresses from the same region. For each sample, 38 variables were used in a multivariate model.

The purpose of this study was two-fold:

- Develop a multivariate model to identify and rank significant variables contributing to the exposure to urban flooding;
- To develop a model to quantify areas prone to urban flooding.

There are, to our knowledge, no other studies using a multivariate model, such as a PLS model, to identify and rank significant variables contributing to urban floods. Some other studies investigating insurance claims and rainfall data have been carried out, but mostly on an aggregated district-level. In a study from the Netherlands and Denmark, a weak relationship was found between property damage and recorded heavy rainfall for summer events, indicating that rain events mainly induce claims the same day [8,9]. Another study [10] concluded that local rainfall statistics were not able to describe the individual cost per claim. However, it was suitable for modelling the overall cost per day. Spekkers et al. [11] used district-aggregated claims to analyze factors influencing urban flooding. They found that claims are most strongly associated with the maximum hourly rainfall intensity followed by the real-estate value, building area, income, household income, and age of the building. Merz et al. [12] stated that to develop reliable damage models, there is a need for more multivariate statistical analyses to look for patterns and interactions between various parameters affecting urban areas.

2. Materials/Access to Data

2.1. Case Area

Fredrikstad is a city with close to 80,000 inhabitants and is situated in Southeastern Norway by the estuary of the river Glomma. The municipal area is 290 km^2, with a relatively long coastline to the Oslo fjord. According to Norwegian standards, it is densely populated.

Fredrikstad’s landscape consists of small valleys and hills that are mainly oriented north-south. The river Glomma also runs north-south and through Fredrikstad, where it frequently causes fluvial flooding [13]. The soil is dominated by clay and there is exposed bedrock in several places throughout the city area, contributing to the amount of impermeable surface areas. In combination with a high groundwater level, this lowers the potential for the infiltration of storm water. Sewers are often located along the lowermost part of the valleys and will often be filled by surface water from the hillsides [14,15].

Indeed, in recent years, the region has experienced numerous pluvial flood events. In the early 2000s, several insurance companies held the municipalities responsible for the damages due to the limited capacity of the sewers and took legal action for a recourse of their pay outs [16]. Heavy rain events in 2006–2008 triggered a similar trial, which ended in a settlement between the two parties. In 2007, a general plan for storm water management in Fredrikstad was launched. One of the intentions of the plan was to create awareness among developers regarding sustainable storm water solutions [17]. Against this background, Fredrikstad was a particularly interesting case for this study.

2.2. Insurance Data

Insurance companies are among those that most rapidly experience the economic consequences of urban flooding, and they initially have to pay compensation for most damages due to floods. For water-related damages in Norway the recent years, only a minor part of the payments were natural hazards, as defined and covered by the Norwegian Natural Perils Pool [18].

The appraisers from most of the insurance companies in Norway are required to use predefined codes to classify the claim as a part of the documentation process. This national database was standardized in 2006 and is administered by Finance Norway, which is the industry organisation for the financial industry in Norway. The market share for the insurance companies using the system in Norway is approximately 90%. All water-related data are coded in three categories [19]:

- Installation: A description of where the malfunction that has led to the damage is located, e.g., water pipes indoor, outdoor, sewer mains;
- Source: A description of the underlying reason for the damage, e.g., precipitation, water supply;
- Cause: Describes the actual cause for the damage, e.g., stop in sewers, aging, frost, malfunction.

Municipalities do not have regular access to Finance Norway’s database of registered flood events on a detailed level. Hence, they have to create their own records to achieve an overview. Information is obtained from their own investigations, mainly based on random contact with residents or from recourse cases. This information has thus become very important when prioritizing flood preventive measures. As a part of Finance Norway's dedication to prevent climate-related damages (or any damage that leads to a claim), their database has been made available for selected research purposes, like this study. Claims specified on addresses are sensitive information, both with respect to personal information and for competitive reasons among insurance companies. Thus, permission was required to obtain access to this data. For this study, the following key-parameters have proven useful:

- Address (property where the damage occurred);
- Compensation sum;
- Classification into codes for Installation, Source, and Cause.

2.3. Geocoding

Geocoding is the process of assigning coordinates to units in a table based on spatial information such as street addresses. Building central points (BCP) is an extract from the Norwegian cadaster, and each point represents a building with a unique address. We used the BCPs to geocode all addresses in the sample. By matching the addresses with the official register (the national cadaster), the coordinates were found. Furthermore, by using text-matching algorithms in python^{tm} (programming language), these units were geocoded. Once the records in a table are geocoded, they add value to the analysis as it is a very effective method for the generation of environmental variables describing the local morphology surrounding the buildings.

2.4. Terrain Parameters

A geographic information system (GIS) was used to generate terrain representations and from these, the terrain variables were extracted. Terrain is commonly represented in GIS using the raster format, where the entire study area is tessellated into a quadratic cell. We generated terrain parameters from digital elevation models (DEM) at three different resolutions (cell sizes): 1, 10, and 50 m, and generated slope and curvature rasters from these. Figure 1 shows the slope values for a small part of Fredrikstad and the inset map is zoomed in on one of the points, representing one of the buildings from the sample. The building point is located within a cell with a slope value of 13.05 degrees, which is the value being assigned as the unit for this variable. However, the location of the building may be anywhere within the cell and possibly towards its edge (as in the inset map in Figure 1). Another variable was added where the slope value was a distance weighted mean of the four nearest pixel values (which in this case equals 18.46). Variables taking the nearest cells into account are referred to as interpolated values.

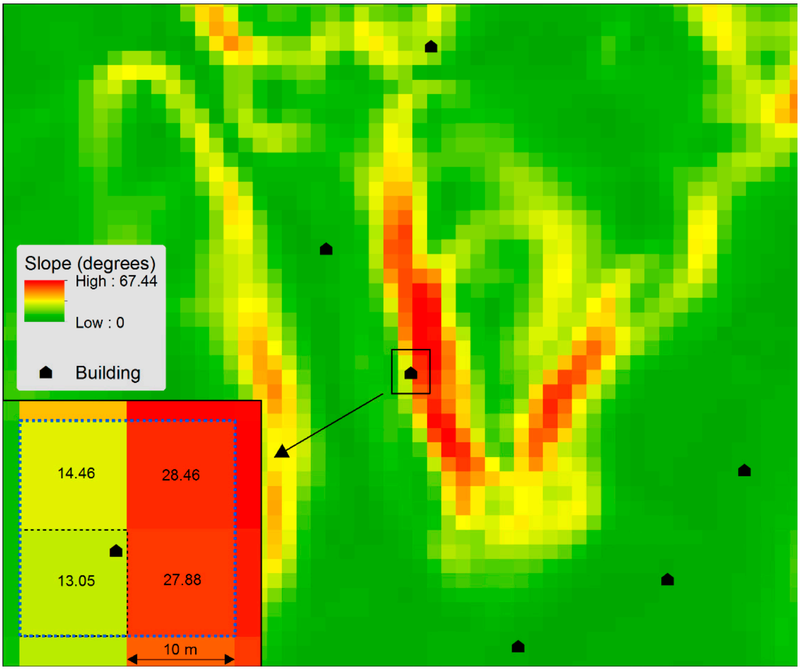

Figure 1. Assigning a slope value for one individual address.

For this study, we have used "Terrain parameters" as a generic term for variables characterizing the location in the field. The selected parameters were all assumed to be flood relevant and divided into four groups:

- *Distance* (elevation z, distance to coast). This group includes the altitude above mean sea level (z) and distance to the coast measured from each building's central points (BCP);
- *Slope* (the slope gradient) includes the slope value from the cells. The variable sl_r100 gives the mean slope within a 100-meter radius for an area elevated higher than the BCP. The other slope values are derived from the cells at the three different resolutions mentioned above;
- *Area* (permeable, impermeable, and sum) was derived from the BCP and arranged in the contributing area into permeable and impermeable surface areas, all within a 100 m radius from the BCP. The upstream sealed area shown in Table 1 was calculated in two ways (abbreviations are explained in Table 1): One includes roads elevated higher than the BCP (a_Up_ro) and another includes all upstream built-up areas (a_US_im) according to [20]. When calculating an upstream area, all cells elevated higher than the BCP were included. This is a limitation, as not all those cells will drain through the BCP. A more accurate way to calculate the upstream drain area might be an opportunity for improvement in further studies. These variables were calculated in a similar way, and we considered that this simplification would not led to statistical bias;
- *Curvature profile (plan and profile)*. Terrain curvature is expressed as the plan or profile curvature, measured along the steepest descent and the contour, respectively. The curvature number is also known as the second derivate value of the input surface by cells, based on the algorithm described by Zevenbergen and Thorne [21].

2.5. Sewer Data

In Fredrikstad, most mains are registered by several variables such as Diameter, Year of Construction, and the Sewer system. Addresses connected to the sewer mains, were either categorized as a part of a combined (single pipe) or separate (two-pipe) sewer system. The combined system dominated until the mid-1960s, when it was substituted by the separate system as an improved method. A comprehensive manual search was carried out for each address to determine the most likely point of connection to the sewer mains, including measuring the distances.

2.6. Sampling

To achieve relevant samples for this study, some inclusion criteria were necessary.

According to the code system, all claims coded Cause = Stop in Sewers/Backflow were selected. These claims are particularly interesting for the municipalities due to the link to sewer mains [22]. There is a possibility that some of these claims are due to other reasons than the mains, e.g., damages or blockage of service pipes. In order to eliminate this, only claims coded as Source = Precipitation were selected. Similarly, a random sample was generated as a reference sample, representing "normal" addresses throughout the case area.

The BCP from the cadaster for the Fredrikstad municipality represented a pool of points from where a random sample was created using the tool Create Random Points available in the ArcGIS® 10.3 software (ESRI, Redlands, CA, USA).

Damage data from the insurance companies were supposed to have locational information such as the street address and unique building identifiers. Of the claims within the inclusion criteria, about 65% unique building identifiers were found and coded. Abbreviations and misspellings were common, but caused no problems.

For this study, it was important to assess the connection point where buildings with a reasonable certainty were linked to the sewer mains. This information is not yet represented as a GIS-layer and variables were therefore generated manually. For 12% of all selected addresses (mainly in the rural area), it turned out to be impossible to determine the connection point to the mains. Finally, some addresses reported as flooded and caused by the sewer, proved to be elevated high above the sewer system. It was unlikely that the sewer mains should have had an impact of these floods. Based on available map information, it was only possible to estimate the vertical distance in integer meters. A threshold was set, and thus all addresses >2 m from the BCP-level to the ground above the sewer mains were eliminated from the dataset. This proved to be 5% of all flooded addresses.

Finally, the dataset consisted of 179 flooded and 168 random addresses. With one exception, random addresses were non-flooded. One single address appeared to be included in both groups and is therefore given special attention in the results section.

3. Method

A goal of this work was to use a set of independent variables linked to each address to predict whether an object belonged to one of two classes (flooded or randomized properties). For this purpose, Partial Least Square Regression (PLS) was chosen. As there were two classes of interest in this study, a special case called Partial Least Square-Discriminant Analysis (PLS-DA) was preferred.

PLS was also found to be suitable due to the high collinearity in the dataset, which may lead to poor results if using, e.g., Ordinary Least Square regression (OLS) [23,24]. Other methods such as Principal Component Analysis (PCA) reduce the number of dimensions and describe the overall variation in the dataset, but only capture the characteristics of the predictors (X). In PLS, the emphasis is on the prediction of the responses (Y). PLS was originally developed as a technique in econometrics, but today, it is primarily used as a tool for chemometrics. Occasionally, PLS is used for environmental studies in order to investigate patterns among variables in environmental studies [25,26]. The software Unscrambler® version 10.3 (CAMO Software AS, Oslo, Norway) was used for this analysis [27].

The dataset for this study consisted of 347 variables. The addresses (X-matrix) had 38 observed feature variables, while the Y-matrix had two classes (flooded or random).

Initially, the PLS-regression started by scaling and constructing linear combinations of the predictors (X) and responses (Y). From the PLS-algorithm, both X and Y matrices were decomposed into matrices of scores and loadings. In PLS, the decomposition process was finalized when the linear combination of the predictors reached its maximum covariance with the responses. In general algebraic terms, this can be written as:

$$X = T \times P^T + E \quad (1)$$

$$Y = U \times Q^T + F \quad (2)$$

P and Q are the loadings and E and F are the residuals (errors) of the X and Y matrices, respectively. The original dataset of X was regressed into t-scores T, which in turn, were used to predict the u-scores U. Finally, the u-scores were used to predict the responses $\hat{Y}$.

To assess the properties for the PLS model, validation was required. As the number of samples was considered to be small, a full cross validation of the dataset was found to be a proper method, as long as the predicted object was not used in the development of the model [28]. During the cross-validation, the dataset was divided into 20 segments. Each segment was left out from the calibration dataset and the model was then calibrated for the remaining objects. Then, the values for the left-out objects were predicted and the residuals were calculated. This process was repeated with another subset of the calibration set until all the segments had been left out once [27].

An approach to solving classification problems is the use of linear regression with dummy responses [29]. This is a binary linear classification (flooded and random). The dummy matrix Y ($n \times 2$) can be defined as:

$$Y_{ki} \overset{\text{def}}{=} \begin{cases} 1, & y_i = \text{member of the class} \\ 0, & y_i = \text{non} - \text{member of the class} \end{cases} \quad i \in \{1, 2 \ldots . n\} \text{ and } k \in \{1, 2\} \quad (3)$$

Furthermore, the scores from the PLS model were used to assign class membership for each address. As we had two classes, the original dummy values could either be 1–0 (flooded) or 0–1 (random). The model predicted two ŷ-values and $\Sigma \hat{y}_i = 1$. An often used approach for assigning the membership of a class is the "winner-takes-all-strategy" and the majority vote [30]. This means that the highest score calculated from the model obtains the class-assignment. Transferred to this study, ŷi, Flooded > ŷi, Random should be interpreted as flooded (F) and vice versa.

The software plots of each sample on a 2D map (score plot) are based on the calculated value related to the factors (latent variables) from the PLS-regression. In the plot, factor 1 will capture most of the variance, factor 2 will capture the second most, etc. In the score plot, two neighbouring samples are more similar with respect to the two factors concerned and vice versa. Likewise, objects located far from each other have different structures. In the loading plot, the predictor's influence on the model is viewed. Adjacent variables are considered to have a high positive correlation and those in diagonally opposite quadrants tend to be negatively correlated. Plots to the far right and left along the factor-1-axis are important for the model, in contrast to those located close to the origin.

Simultaneous interpretations of scores and loadings are probably the most useful feature of a PLS-plot. A sample located to the right in the score plot usually has a large value for variables to the right in the loading plot, and vice versa. In this study, samples were labelled in the score plot, as flooded or randomized addresses. By comparing the scores and loading plot, the characteristics of the two classes can be explained [27].

4. Results

All variables used in the PLS-analysis are shown in Table 1.

Table 1. Variables included in the PLS-analysis.

Group	No	Abbrev.	Parameter	Flooded (F) Addresses		Random (R) Addresses		BCP = Building Central Point Comments
				Aver	(SD)	Aver	(SD)	
Distance	1	d_C	Distance to coast	627	(415)	639	(471)	Distance from BCP to coast (m)
Distance	2	d_z1	elevation_1m area	14.95	(11)	22.61	(14)	Elevation extracted from 1 m resolution DEM at location of BCP
Distance	3	d_z10	elevation_10m area	15.34	(11)	22.60	(14)	As above, 10 m resolution
Distance	4	d_z50	elevation_50m area	15.80	(11)	22.57	(14)	As above, 50 m resolution
Slope	5	sl_1	slope_1m	2.6	(3,1)	5.1	(4,6)	Mean slope extracted from 1 m resolution DEM at location of BCP
Slope	6	sl_10	slope_10m	2.2	(2,2)	5.3	(4,2)	As above, 10 m resolution
Slope	7	sl_50	slope_50m	2.3	(2,1)	3.9	(2,9)	As above, 50 m resolution
Slope	8	sl_r100	Slope_r100	5.9	(3,8)	7.7	(3,9)	Mean slope extracted from 100 m radius at location of BCP
Slope	9	sl_1_ip	slope_1m interpolated	2.6	(3,1)	5.1	(4,6)	Mean slope extracted from 1 m resolution DEM at location of BCP and its 8 first neighbors
Slope	10	sl_10_ip	slope_10m interpolated	2.2	(2,3)	5.5	(4,2)	As above, 10 m resolution
Slope	11	sl_50_ip	slope_50m interpolated	2.4	(2,0)	3.9	(2,6)	As above, 50 m resolution
Area	12	a_Up	UpSlope area	18,047	(4934)	13,171	(5381)	Area at higher ground than BCP within 100 m radius
Area	13	a_Up_ro	UpSlope impervious area	1761	(941)	999	(840)	Roads(impervious) at higher ground than BCP within 100 m radius
Area	14	a_RUp_ro	Rate UpSlope impervious area	0.10	0.05	0.07	0,05	Ratio No. 13/No. 12
Area	15	a_DS	Cells downstream	13,382	(4957)	18,183	(5407)	Area at lower ground than BCP within 100 m radius
Area	16	a_US	Cells upstream	17,986	(4957)	13,186	(5407)	Area at higher ground than BCP within 100 m radius
Area	17	a_US_im	Cells impervious	15,880	(5168)	11,167	(5528)	Area of imperm surfaces at higher ground than BCP within 100 m radius
Area	18	a_US_pe	Cells pervious	2106	(3158)	1966	(3761)	Area of perm. surfaces at higher ground than BCP within 100 m radius
Area	19	a_RUS_im	Rate Cells impervious	0.89	(0,2)	0.86	0,24	Ratio No. 17/ No. 16
Curvature	20	c_pr1	curvature profile 1 m	0.16	(1,7)	−0.17	(3,0)	Profile curvature extracted from 1 m resolution DEM at location of BCP
Curvature	21	c_pr10	curvature profile 10 m	0.07	(0,3)	0.04	(0,6)	As above, 10 m resolution
Curvature	22	c_pr50	curvature profile 50 m	0.07	(0,1)	−0.01	(0,1)	As above, 50 m resolution
Curvature	23	c_pr1_ip	curvature profile 1 m interpolated	0.14	(1,2)	−0.13	(2,1)	Weighted mean profile curvature extracted from 1 m resolution DEM based on four closest pixels to location of BCP
Curvature	24	c_pr10_ip	curvature profile 10 m interpolated	0.08	(0,2)	0.03	(0,6)	As above, 10 m resolution
Curvature	25	c_pr50_ip	curvature profile 50 m interpolated	0.06	(0,1)	0.00	(0,1)	As above, 50 m resolution
Curvature	26	c_pl1	curvature plan 1 m	0.18	(1,9)	0.02	(1,8)	Plan curvature extracted from 1 m resolution DEM at location of BCP
Curvature	27	c_pl10	curvature plan 10 m	−0.02	(0,2)	0.06	(0,3)	As above, 10 m resolution
Curvature	28	c_pl50	curvature plan 50 m	−0.02	(0,1)	0.03	(0,1)	As above, 50 m resolution
Curvature	29	c_pl1_ip	curvature plan 1 m interpolated	0.14	(1,4)	0.05	(1,5)	Weighted mean plan curvature extracted from 1 m resolution DEM based on four closest pixels to location of BCP
Curvature	30	c_pl10_ip	curvature plan 10 m interpolated	−0.02	(0,1)	0.06	(0,3)	As above, 10 m resolution
Curvature	31	c_pl50_ip	curvature plan 50 m interpolated	−0.02	(0,0)	0.02	(0,1)	As above, 50 m resolution
Sewer	32	se_C	Combined sewer mains (rate)	66%		46%		Rate combined system (category var)
Sewer	33	se_S	Separate sewer mains (rate)	34%		54%		Rate separate system (category var)
Sewer	34	se_D	Diameter pipe(mm)	369	(225)	269	(134)	Diameter of nearest sewer pipe
Sewer	35	se_Y	Year of constructed pipe	1972	(26,2)	1974	(23,0)	Year of construction for the nearest sewer mains
Sewer	36	se_HorD	Horizontal dist to sewer	20.9	(9,9)	29.2	(23,3)	Horizontal distance from BCP to the nearest sewer
Sewer	37	se_V>2	Vertical dist to sewer >2 m	0%		16%		Vertical distance from BCP to sewer mains >2 m (category variable)
Sewer	38	se_V<2	Vertical dist to sewer <2 m	100%		84%		Vertical distance from BCP to sewer mains<2 m (category variable)

In Table 1, the two classes, flooded (F) and random (R), are shown. Due to limited space for text in the plot, abbreviations were needed for labelling the samples and variables. A full label and a brief description of each variable, as well as average and Standard Deviation-values (SD), are shown in Table 1. Some distinctions appear among the classes. For example, it makes sense that flooded houses on average are lower elevated (d_z1) and more associated with a combined sewer system (se_C) than random houses (abbreviations are explained in Table 1). For this study, a PLS model was used to reveal the internal structure and the significance of the individual variables according to their sensitivity to flood-risk. To handle the input variables on a common scale during the PLS-regression, each variable was divided by its standard deviation.

In terms of classification using the winner-takes-all-strategy, 84% of initially flooded houses were correctly classified. Correspondingly, the number for randomized houses was 68%. This indicates that 32% of the random addresses tend to have the attributes of flood-prone homes. Conducting a 2 × 2 confusion matrix for the validated responses, the over all accuracy was calculated as being 76.4%. As most of the objects were correctly classified, this model was considered as reliable for further analysis.

The output from the PLS-DA model in terms of the score and loading plot is shown in Figure 2. These plots form the basis of the interpretation of single variables in the discussion section. Numbers in brackets display the variance for X-data and Y-data for Factor-1 and Factor-2 (latent variables). From Figure 2, it was calculated that the first two factors in the sum described 27% and 36% of the variance in the dataset for X and Y, respectively. The explained variance for the model showed that even more factors did not capture more of the variance.

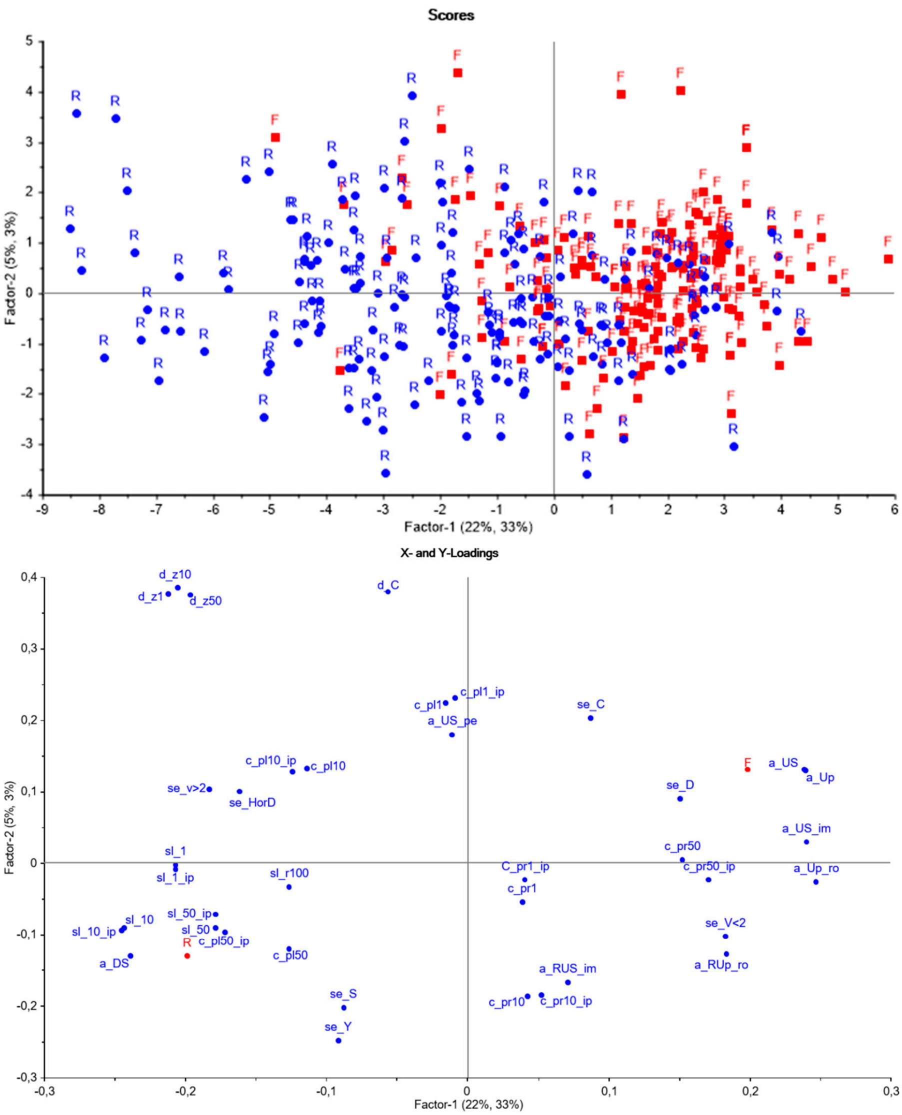

Figure 2. Scores (upper plot) and loadings (lower plot) computed from PLS.

Figure 2 shows a 2D plot for Factors 1 and 2 from the PLS-regression. In the score-plot, the red-marked dots (F) are mostly located at the right-hand side (positive value of Factor 1), while most of the random data is at the left-hand side. The separation between the red and blue marked dots indicates the different structures between the two classes. This suggests that this difference is mainly explained by Factor-1. It is hard to discriminate the classes along the Factor-2 axis (or any other factors at higher levels).

As mentioned above, one single address was included in both samples. This address was plotted twice at 1.22, −2.88 in the score plot in Figure 2. As this address is exposed to flooding, it was further confirmed in the validation-process.

The loading plot in Figure 2 shows the importance of each variable in relation to Factor 1 and Factor 2. The variables derived from the upstream area are found to at the far right, while the slope, elevation, and downstream areas are found at the opposite side.

The scattered nature of the variables shown in Figure 2.

5. Discussion

An analysis of the scores and loadings in Figure 2 suggests that the rate of the impervious and upstream area surrounding the BCP is the most significant characteristic for a flood-prone property. All four variables rightmost in the loading plot belong to this group, just as flooded samples are to the right in the score plot. a_US and a_DS are inversely correlated, and this follows from the exact number of cells surrounding the BCP (abbreviations are explained in Table 1). For a given range, the area surrounding the house is equal, and thus, a large proportion of the area at a higher altitude correspondingly means a smaller area downstream. It seems that the area of permeable surfaces (a_US_pe) has little impact, as this variable is plotted close to the origin in the score plot. The plot clearly confirms a well-known phenomenon that a higher proportion of sealed areas increases the runoff and the risk of flooding. A large amount of this area is probably on built-up private grounds. Taking this into account, the municipality, both as the developer and authority, plays an important role in informing citizens and making them aware of the great impact that impermeable surfaces have on the downstream flood risk. Variables characterizing the average slope suggested that homes at risk of flooding are more often in flat areas. At steep slopes, floodwater will probably just pass the houses and do not cause any harm. Another flood-type, a flash flood, occurs when heavy rain is collected in the slopes and immediately drains to rivers that originally hold very little or no water. This can be particularly dangerous, since the water level rises suddenly and is difficult to forecast. In 2003, a so-called Flash Flood Potential Index (FFPI) was presented [31] Originally, this index was based on an equal weighting of the parameters; slope, land use, soil type, and vegetation cover. Later, the model was developed and the slope was given a slightly higher weight [32].

Variables describing distance to the sea (d_C did not seem to matter to the model. Generating this variable was intended to assess whether high tide and seawater in the sewer decrease the flow velocity and lead to flooding for houses close to the coastline. Elevation (z) turned out to be of great importance for the model and was inversely correlated with flood-prone homes. There might be two explanations for this. First, low-lying houses are simply more exposed to flooding than houses higher up. Secondly, the oldest part of the city is low-lying, with a higher portion of sealed surfaces and older sewers. The latter appears in Figure 2, as the variables measuring a dense area (a_Up_ro and a_US_im) and a combined sewer system (se_C) are located on the right side and are inversely correlated to the elevation z.

Terrain curvature determines whether a given part of a surface is convex or concave. For plan and profile curvature, the sign rules are inversely defined, and a negative and positive number, respectively, describes the concavity. Profile curvature indicates the form of the surface in the steepest direction and whether the terrain flattens into a concave curvature. The flow of surface water will lose speed and water will accumulate. Figure 2 indicates that this variable is important for a map-resolution of 50 m × 50 m and the fact that the most flood-prone areas are located in concave landscapes. The curvature number calculated for 1 DEM in Figure 2 is found close to the origin, and hence, is less significant. This indicates that when assessing the flood-risk vs. the shape of the terrain, we have to look at a slightly larger area.

The loading plot shows that the oldest sewer system (combined) with larger pipes correlates best with the flooded addresses. The random addresses are more likely to be located close to the separate sewer system. These observations are not surprising, due to the historical background of the type of sewer systems. Anyway, it should be noted that the rate of the upstream sealed area seems to have more impact on the model than the type of sewer system.

This study covers urban floods, which mainly do harm in densely populated areas, due to the lack of drainage capacity. A comparison between the FFPI-index and this study illustrates distinct differences between the two flood types. As steeper slope is characteristic of areas where a flash flood occurs, this study clearly shows that the portion of sealed surface and a little slope have more impact on pluvial floods in urban areas.

6. Conclusions

This paper highlights features of flood-prone properties in urban areas mostly caused by the insufficient capacity of the sewer system. From the PLS regression, the model predicts whether a property is prone to flood or not, with an acceptable uncertainty. The validated model correctly categorised 84% of all claims.

The variables are of different importance for the model. Even though all floods in this study are associated with the sewer system, the area in general and especially the portion of sealed surface on properties above the house, were important for the model. It makes sense that the results from the model indicate that flooding tends to occur in flat areas with a concave curvature. Furthermore, houses located on steep slopes seem to be less exposed. Possibly the most interesting aspect in this study is that the method makes it possible to rank and quantify significant variables for urban flooding. Furthermore, from the model, it is possible to predict if a property has the features of a flood-affected house. All variables in the study are related to exposure and cover only a part of all possible factors determining the flood risk. However, they are computationally fast to obtain and the result can make it easier to prioritize preventive measures, which can further contribute to a reduced flood risk.

Traditionally, the improvement of the drainage system in flooded areas means renovating pipes and replacing a combined system with separate sewers. However, the trend in cities worldwide is to construct more sustainable urban drainage systems (SUDS). This implies more non-piped solutions and handling storm water on the surface for infiltration, retention, and structured transportation paths. SUDS is believed to be more cost-effective and environmentally friendly than "just" upgrading piped solutions to cope with an increased flood risk [33,34]. This work shows that an emphasis should be placed on reducing the fraction of sealed surface rather than renovating old sewers that are still working, but with a limited capacity. With an expected increase in urban flooding [33,35], this will become even more crucial the coming years.

This work shows that PLS-DA is a suitable tool for predicting whether a property is flood-prone. The opportunities for visualizing PLS-plots are particularly good as the samples associated with different classes can be labelled. This makes it easier to explain and interpret the results. The score and loading values from this model can potentially be further developed and predict risk zones that can support more comprehensive and dynamic hydraulic models.

There are obviously limitations, and as we see from Figure 2, only 36% of the variance in the responses was captured by the two first factors in the model. However, most of the outcomes from this study make sense; they are restricted to this case area and for a certain time period. More samples in the dataset, in terms of addresses and events, would have made the conclusions more significant. Manual methods used to determine sewer data can be a source of error and should be developed so that they can be extracted digitally. Hence, there was no indication of incorrect data. In this study, a building, which occupies an area, is represented with one point, and this is a crude representation.

Other variables could have been included (e.g., age of property, level of basement floor, state of the service pipes) and possibly improved the model. If rainfall data were available for specific events and addresses, this could be included in the dataset and would probably improve the model. Similarly, e.g., socioeconomic variables could have been used to explain the vulnerability to floods. However, they are believed to be more inaccurate and time-consuming to obtain and out of scope for this study.

Even though this dataset is tested for one location, the conditions leading to urban floods are quite similar to other parts of Scandinavia. Applying this method with data from other cities, the outcome of this study can be further evaluated and compared. This could possibly induce an urban flood index within a region that characterizes the exposure to potential floods. Further, the results of such studies can provide premises when placing houses in new residential areas.

Individuals' risk awareness before water enters buildings is found to considerably reduce the damage cost. Based on their knowledge of flood risk, people can protect their properties better. In a study [36], this was found to reduce content damages by an average of 90% in the case of basement floods. According to Khakpour [37] and Botzen et al. [38], a risk-based premium classification could motivate property owners to invest in measures adapting to flooding. In this context, predicting and quantifying the exposure to urban floods can be a useful tool, not only for the authorities, but also for insurance companies, developers, and property owners. A good starting point is to make individuals aware of the risk. This may also motivate them to implement simple, and often inexpensive, flood prevention measures.

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- Geir Torgersen: conception and design of the work, analysis, interpretation and drafting;
- Jan Ketil Rød: design of the work, analysis and interpretation;
- Knut Kvaal: design of the work, analysis and interpretation;
- Jarle T. Bjerkholt: conception and design of the work, analysis and interpretation;
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References

1. Dawson, R.; Speight, L.; Hall, J.; Djordjevic, S.; Savic, D.; Leandro, J. Attribution of flood risk in urban areas. *J. Hydroinform.* **2008**, *10*, 275–288. [CrossRef]
2. *Government U.K. Foresight Future Flooding*; Office of Science and Technology: London, UK, 2004.
3. Nyeggen, E. Gjensidige Forsikring Climate Change—New Challenges for the Insurance Industry? (Translated). Available online: http://www.forsikringsforeningen.no/wp-content/uploads/2012/08/2007-Nyeggen.pdf (accessed on 2 March 2017).
4. Finance Norway VASK—National Register of Water Damages (Translated). Available online: http://www.finansnorge.no/statistikk/skadeforsikring/vask/ (accessed on 2 March 2017).
5. *Special Report of IPCC 2012: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2012; p. 582.
6. Crichton, D. *Flood Plain Speaking*, 3rd ed. Available online: http://www.cii.co.uk/knowledge/claims/articles/flood-plain-speaking/16686 (accessed on 16 October 2015).
7. Kaźmierczak, A.; Cavan, G. Surface water flooding risk to urban communities: Analysis of vulnerability, hazard and exposure. *Landsc. Urb. Plan.* **2011**, *103*, 185–197. [CrossRef]
8. Spekkers, M.H.; Ten Veldhuis, M.-C.; Kok, M.; Clemens, F. Analysis of pluvial flood damage based on data from insurance companies in the Netherlands. In Proceedings of the International Symposium Urban Flood Risk Management, UFRIM, Graz, Austria, 21–23 September 2011; Zenz, G., Hornich, R., Eds.; Technische Universitat Graz: Graz, Austria, 2011.

9. Spekkers, M.; Zhou, Q.; A.-N., K.; Clemens, F.; Veldhuis, M.-C.T. Correlations between rainfall data and insurance damage data related to sewer flooding for the case of Aarhus, Denmark. In proceedings of the International Conference on Flood Resilience: Experiences in Asia and Europe, Exeter, UK, 5–7 September 2013.
10. Zhou, Q.; Panduro, T.E.; Thorsen, B.J.; Arnbjerg-Nielsen, K. Verification of flood damage modelling using insurance data. *Water Sci. Technol.* **2013**, *68*, 425–432. [CrossRef] [PubMed]
11. Spekkers, M.H.; Kok, M.; Clemens, F.H.L.R.; ten Veldhuis, J.A.E. Decision-tree analysis of factors influencing rainfall-related building structure and content damage. *Nat. Hazards Earth Syst. Sci.* **2014**, *14*, 2531–2547. [CrossRef]
12. Merz, B.; Kreibich, H.; Lall, U. Multi-variate flood damage assessment: A tree-based data-mining approach. *Nat. Hazards Earth Syst. Sci.* **2013**, *13*, 53–64. [CrossRef]
13. Aall, C.; Øyen, C.; Hafskjold, S.; Almås, A.; Groven, K.; Heiberg, E. Klimaendringenes Konsekvenser for Kommunal og Fylkeskommunal Infrastruktur. Delrapport 5. Available online: http://www.vestforsk.no/filearchive/r-ks-hindringsanalyse.pdf (accessed on 4 May 2017).
14. Nie, L.; Lindholm, O.; Lindholm, G.; Syversen, E. Impacts of climate change on urban drainage systems—A case study in Fredrikstad, Norway. *Urb. Water J.* **2009**, *6*, 323–332. [CrossRef]
15. Børstad, B. *Fredrikstad Municipality, Flood Event 7. September 2002, Documentation of Rainfall and Sewers, Part 1 of 3 (Translated)*, COWI: Fredrikstad, Norway, 2007.
16. Lindholm, O.; Schilling, W.; Crichton, D. Urban Water Management before the Court: Flooding in Fredrikstad, Norway. *J. Water Law* **2006**, *17*, 204–209.
17. *Fredrikstad Municipality Master Plan for Drainage and Storm Water (Translated)*; Fredrikstad Municipality: Kommune, Norway, 2007.
18. Ebeltoft, M. *Climate Change Makes New Challenges and Force New Solutions—Using Insurance Data as a Preventive Measure (Translated)*; Finance Norway: Oslo, Norway, 2012.
19. Finance Norway. *Explanation of the Codes in VASK—National Register of Water Damages (Translated)*. Available online: https://vask.fno.no/OmKoder.aspx (accessed on 2 March 2017).
20. NFRI Documentation of AR50 (area categories). Available online: http://www.skogoglandskap.no/artikler/2007/nedlastingsinfo_ar50/newsitem (accessed on 2 March 2017).
21. Zevenbergen, L.W.; Thorne, C.R. Quantitative analysis of land surface topography. *Earth Surf. Process. Landf.* **1987**, *12*, 47–56. [CrossRef]
22. Brevik, R.; Aall, C.; Rød, J.K. Pilot Project on Testing of Damage Data From the Insurance Industry for Assessing Climate Vulnerability and Prevention of Climate-Related Natural Perils in Selected Municipality (Translated). Available online: http://www.vestforsk.no/filearchive/vf-rapport-7-2014-testing-av-skadedata.pdf (accessed on 2 March 2017.
23. Farahani, H.A.; Rahiminezhad, A.; Same, L.; immannezhad, K. A Comparison of Partial Least Squares (PLS) and Ordinary Least Squares (OLS) regressions in predicting of couples mental health based on their communicational patterns. *Procedia—Soc. Behav. Sci.* **2010**, *5*, 1459–1463. [CrossRef]
24. Tobias, R.D. An introduction to partial least squares regression. In Proceedings of the SAS Users Group International 20 (SUGI 20), Orlando, FL, USA, 2–5 April 1995; pp. 2–5.
25. Nash, M.S.; Chaloud, D.J. Partial Least Square Analyses of Landscape and Surface Water Biota Associations in the Savannah River Basin. *ISRN Ecol.* **2011**, *2011*. [CrossRef]
26. Zhang, H.Y.; Shi, Z.H.; Fang, N.F.; Guo, M.H. Linking watershed geomorphic characteristics to sediment yield: Evidence from the Loess Plateau of China. *Geomorphology* **2015**, *234*, 19–27. [CrossRef]
27. Camo. *The Unscrambler—User Manuals 2015*; CAMO software AS: Oslo, Norway, 2015.
28. Westerhuis, J.A.; Hoefsloot, H.C.J.; Smit, S.; Vis, D.J.; Smilde, A.K.; Velzen, E.J.J.; Duijnhoven, J.P.M.; Dorsten, F.A. Assessment of PLSDA cross validation. *Metabolomics* **2008**, *4*, 81–89. [CrossRef]
29. Indahl, U.G.; Martens, H.; Næs, T. From dummy regression to prior probabilities in PLS-DA. *J. Chemom.* **2007**, *21*, 529–536. [CrossRef]
30. Pérez, N.F.; Ferré, J.; Boqué, R. Calculation of the reliability of classification in discriminant partial least-squares binary classification. *Chemom. Intell. Lab. Syst.* **2009**, *95*, 122–128. [CrossRef]
31. Smith, G. *Flash Flood Potential: Determining the Hydrologic Response of FFMP Basins to Heavy Rain by Analyzing Their Physiographic Characteristics*; NWS Colorado River Forecast Center: Salt Lake City, Utah, USA, 2003.

32. Zogg, J.; Deitsch, K. *The Flash Flood Potential Index at WFO Des Moines, Iowa*; National Weather Service Forecast Office: Des Moines, IA, USA, 2013.
33. Willems, P. *Impacts of Climate Change on Rainfall Extremes and Urban Drainage Systems*; IWA Publishing: London, UK, 2012; p. 226.
34. Cettner, A. *Overcoming Inertia to Sustainable Stormwater Management Practice*; Luleå University of Technology: Luleå, Sweden, 2012.
35. Jha, A.K.; Bloch, R.; Lamond, J. *Cities and Flooding: A Guide to Integrated Urban Flood Risk Management for the 21st Century*; World Bank Publications: Washington, DC, USA, 2012.
36. Van Ootegem, L.; Verhofstadt, E.; Van Herck, K.; Creten, T. Multivariate pluvial flood damage models. *Environ. Impact Assess. Rev.* **2015**, *54*, 91–100. [CrossRef]
37. Khakpour, M. As Temporal as Spatial: It is Geographical: Exploring Spatio-Temporality in Modeling the Risk of Climate Change and Natural Hazard. Ph.D. Thesis, Norwegian University of Science and Technology, Trondheim, Norway, 2015.
38. Botzen, W.J.W.; Aerts, J.C.J.H.; van den Bergh, J.C.J.M. Willingness of homeowners to mitigate climate risk through insurance. *Ecol. Econ.* **2009**, *68*, 2265–2277. [CrossRef]

Paper IV

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Singing in the rain: Valuing the economic benefits of avoiding insecurity from urban flooding

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Singing in the rain:

Valuing the economic benefits of avoiding insecurity from urban flooding

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Abstract

Avoiding households´ fear of urban flooding damages during heavy rain is a benefit component often overlooked in Cost-Benefit Analysis (CBA) of measures preventing these damages. A Contingent Valuation (CV) survey shows that the monetary value of the welfare gain to Norwegian households from avoiding this insecurity can be substantial. Households who feel exposed and live close to areas with previous urban flooding, have higher willingness to pay (WTP) in terms of increased municipal charges, to avoid insecurity than those that live further away. We discuss how such measures of "closeness to flooding" can be used in future CBAs of measures preventing urban flooding. Adding the benefits of reduced insecurity in CBAs could justify higher investment in urban flood prevention.

Introduction

Urban flooding occurs mainly during heavy rainfall in densely populated areas, often with insufficient drainage and sewer systems. This is known as *pluvial flooding*, as opposed to fluvial floods, which are strongly related to overflowed rivers. Although pluvial floods cause lesser damage per event than fluvial, the pluvial ones occur more frequently and can thus still cause high aggregate costs to the society. These social costs might increase over time as climate change likely increases the frequency of extreme rainfall events, and the urban population and wealth grow (Tait et al., 2008, Semadeni-Davies et al., 2008, Willems, 2012, Cettner et al., 2012). Pluvial as well as fluvial floods across Europe the last years clearly show the large impact flooding can have in many cities. The total losses of flooding in UK during the summer of 2007, was estimated to be about £4 billion (€6,9 billion 2015) (Chatterton et al., 2010). In Copenhagen a cloud burst in less than three hours 2 July 2011, caused floods with a cost of 6 billion Danish kroner (€0,85 billon 2015) (Rasmussen, 2014).

There are two main categories of preventive measures against pluvial flooding: i) structural measures, and ii) non-structural measures. Structural measures aim to reduce flood risk by managing the flow from outside or within urban settlements. These range from hard-engineered measures like new pipes to "softer" measures like natural ponds. Non-structural measures intend to keep people safe from flooding through emergency preparedness, warning systems, and sustainably developed or well-planned urban areas. Measures from both groups are complementary, and can be implemented simultaneously (Jha et al., 2012). Often, the local authorities have to prioritize among a number of pluvial flood prevention measures and projects. Cost-Benefit Analysis (CBA), which quantifies and values (in monetary terms) all social benefits and costs to all affected interest groups over the life time of a projects (Boardman et al 2011), can be a useful tool for ranking such projects.

While CBAs are routinely used in Norway for project evaluation in general (see the national guidelines for CBA NGAF, 2014) and for infrastructure projects in particular (see e.g.NPRA, 2014) for the CBA handbook for road projects), CBAs are rarely used to rank urban flooding prevention projects. This might be because every single damage and required investment so far has been relatively small. However, on the aggregate level, both costs and benefits can be substantial, as thus CBA can be a very useful decision support tool.

Flooding in cities result in a number of social costs such as traffic disturbance, damage to infrastructure and buildings (both residential and commercial), insecurity among people fearing new floods, sick leave due to polluted water, lost lives, lost sales for businesses, and pollution of drinking water and local lakes and rivers (Lindholm et al., 2008). Chatterton et al (2010) found insecurity and psychological stress to be the second most costly sub-item for society in the 2007 fluvial flood in England (Chatterton et al., 2010). Only the damage costs to residential houses and businesses were higher.

According to Elvik (2006), insecurity can be regarded as sense of lack of or insufficient level of safety. For individuals, insecurity in itself will be a burden, in terms of worrying about the impacts of flooding such as real estate value loss, additional clean-up work, vermin in the basement etc., even if the flooding does not occur. Security against flooding can be considered as a public good like clean air and water and access to urban parks, which obviously has a value to humans although they do not have a market price. While private goods can be valued using market prices, stated preference (SP) and revealed preference (RP) methods are needed to value changes in the quality or quantity of such public goods as environmental quality and flood insecurity (Messner et al., 2007, Navrud and Magnussen, 2013). As SP methods can value future changes in both the use and non-use value of public goods, they are frequently used. The SP methods, Choice Modelling (CM) and Contingent Valuation (Bateman, 2002), can value the welfare loss from flooding; (see e.g. Brouwer et al., 2007 for applications of the CM and CV method, respectively, Navrud et al., 2012)). While there have been CV surveys assessing insecurity from fluvial floods (Botzen et al., 2009, Grann, 2011, DEFRA/EAF, 2004), there are, to our knowledge, no applications of the CV method to value insecurity from pluvial floods.

The main aim of this study is therefore to apply the CV method to estimate households´ willingness-to-pay (WTP) to avoid the insecurity from pluvial floods in urban areas, as a measure of the social benefits of avoiding this loss in their wellbeing. We further aim to test the validity of the CV survey by exploring how households´ WTP vary with income and other demographic variables, as well as the level of pluvial flood exposure, experience and anxiety. Finally, we aim to show how our results can best be used in future CBAs of measures preventing pluvial floods in urban areas. For the rest of this paper, pluvial floods in urban areas will be referred to as “urban floods”.

The remains of this paper is organized as follows: The next section describes the sample, design process and final outline of our CV survey. The third section reports and discusses the main survey results, and explores what factors determine households´ WTP, including demographic variables and how exposed and affected people are by urban floods. The fourth section presents the welfare measure of insecurity in terms of mean WTP/household/year. The final section discusses how these estimates can be used in CBAs of measures to prevent urban floods, and concludes.

Contingent Valuation (CV) survey and CV scenario design

CV surveys can be carried out by telephone, mail, face-to-face interviews, and lately increasingly by internet surveys (from lists of e-mail addresses) or internet panel surveys (where professional survey companies have recruited a panel of people to answer internet surveys). According to Lindhjem and Navrud (2011), internet panel surveys perform just as well as the previous ”golden standard” of face-to-face interviews, and if any difference in WTP between these two survey modes, estimates seem to be lower in internet surveys. Thus, in Norway, with more than 95 % of the population having access to internet, an internet panel survey was found to be the most cost and time effective survey mode for our survey.

The CV internet panel survey was conducted in March and April 2016, with a random sample of 1060 respondents across Norway. Each respondent represented a household, which was at different levels of exposure to urban floods. The response rate was 25,1 %, which is considered satisfactory in internet surveys, especially since we were not aiming for a representative sample of the overall Norwegian population. Rather, we aimed for a random sample of urban households being exposed to urban floods at different levels; from “no exposure” to “very much exposed”. This enables the estimation of welfare estimates for each level of exposure, which are better adapted for use in future CBAs of flood prevention measures. Members of the internet panel, living in urban and suburban areas within postal codes where urban flood events had been recorded in recent years, were in the target group. They were chosen in order to get a sufficient number of households exposed to urban floods. The postal code areas are large, and there would also be other households in the sample that were not exposed to urban floods, and thus all levels of exposure would be covered. . Midway through the survey, we found that only about 5% of respondents stated that they were “quite", "much” and “very much" exposed to urban floods. In order to get a higher number of respondents that were exposed, and a more reliable WTP estimates for these exposed households, we introduced an initial screening question. This allowed only those stating they were prone to flooding to respond. Thus, in the final net sample, 19,8 % of the respondents were quite, much or very much exposed to urban flooding. Note, however, that in Norway overall, probably much less than 5 % are exposed to urban flooding, and that our numbers is a result of our sampling and screening procedures.

The survey instrument was developed and pretested; starting with one-to-one interviews (Bateman, 2002). Six people randomly drawn from the internet panel (representing both genders, different age groups and educational levels) attended this session at a central facility. Three out of six were pre-selected to have experienced floods in order to test the survey instrument also on those with flood experience. (A random sample of six would likely have resulted in none having experienced flood). These respondents completed a first version of the internet survey, talking aloud about their responses, while we sat beside them, taking notes and asking clarifying follow-up questions (These sessions were recorded on video, and evaluated afterwards). This first pre-test led to re-writing of questions to make them clearer. We also changed the payment vehicle from increased sewage bill to an increase in the overall municipal charges (of which the sewage bill is a part), which the respondents seem to be more familiar with. The second pre-test involved distributing the revised survey to 30 respondents.

The most important finding from this pretest was that people were confused by the randomization of the order of the two CV scenarios (A "Preventive measures" and B "Insurance"; see below for details) they were asked to value. This was especially true for those who got the less comprehensive scenario B before A. To avoid this confusion, WTP for the most comprehensive, scenario A, was always asked before B in the final survey. They were also given advance notice that they would be asked their WTP for both scenarios.

In order to get a high response rate (and thus a more representative sample) and valid responses, survey questions should be asked in logical order, be concise, clear and be single questions (i.e. not asking for more than one thing in the same questions). According to Alberini and Kahn (2006) and McMahon et al. (2000) terms and valuation scenarios should be well-defined without scientific jargon. Our final questionnaire consisted of the following five parts:

(1) Introductory part that put urban floods in a broader context, and helps respondents to distinguish between different levels of flooding from precipitation, and identify the level we are looking at (defined as level 2 in table 1; and termed "urban floods" here)
(2) Attitudinal and behavioral questions
(3) Two CV scenarios (A: "Preventive measures" and B: "Insurance") with accompanying WTP questions (wtpA and wtpB, respectively), which were used to elicit respondents´ WTP for avoiding insecurity from urban floods (se description below)
(4) Follow-up questions about the reasons for being willing to pay or not
(5) Questions about demographic variables (age, education, gender etc.) and personal and household income.[1]

Regarding part (3) and following (Grann, 2011), households´ WTP for avoiding insecurity from urban floods was estimated as the difference in their WTP for two CV scenarios; A and B. Firstly, in scenario A, respondents were asked the most they were willing to pay in increased annual municipal charges for the local authorities to implement measures that would fully prevent all urban floods (wtpA). Secondly, in scenario B, they were asked the most they were willing to pay for an additional home insurance that would cover all their future damages from urban flooding, including their current deductible (wtpB). Thus, in both scenarios, they would pay to have no personal costs from the flooding; i.e. in scenario A there would not be floods, and in scenario B they would get all their physical damage costs covered. However, in scenario B they would still have the insecurity from knowing that urban flooding could occur. Thus, the difference between wtpA and wtpB reflects households´ WTP to avoid insecurity for urban flooding; defined as wtpAB = wtpA – wtpB.

Parts (2) and (5) provided data on households´ attitudes, behaviour, experiences with flooding, demographics and income that were used to test the validity of their WTP responses. We were particularly interested in testing whether their responses were in accordance with expectations from economic theory (Bateman, 2002). Thus, in this study we wanted to test whether:

[1] Income questions were asked in the last part of the survey, as they could invoke negative feeling among some respondents and made them exit the survey early on if placed in the beginning.

- Household WTP increases with household income
- Household WTP increases with more experience or exposure to flooding, i.e. what we had termed "Closeness to flooding"
- Household WTP is higher for the more inclusive good, i.e. scenario A: "Preventive measures" (which avoids all damage costs *and* insecurity) than B: "Insurance" (which avoids all damage costs, but not the insecurity). This is also termed an (internal) "scope test", which is passed for households with wtpA > wtpB (wtpA = wtpB could occur if people have zero WTP to avoid insecurity, while wtpA < wtpB would not be rational, and will not pass the test).

Regarding part (1), table 1 was shown to the respondents in order for them to distinguish between the different levels of flooding from precipitation, where level 2 is what we defined as "urban flooding", which was the subject of the CV scenarios.

Table 1:

The survey focused on "Level 2-floods" (Urban floods). This expression "Level 2-floods" was mentioned several times throughout the internet survey, and each time respondents could just click on that text to get the explanation shown in table 1 repeated in a pop-up box. During the pre-test, we noticed that some respondents confused level 2 with water pipe leaks, which also can lead to harmful flooding, but this was not the subject of this survey. Therefore, we added a question about whether they had experienced water pipe leaks or not, and afterwards made clear that this survey was about flooding from precipitation only.

A realistic and fair payment vehicle connected to the provision of the public good is essential in order to get valid WTP. As insufficient sewer mains and limited drainage of water in public areas are the most common causes for level-2 floods, charges connected to sewage disposal seemed to be an appropriate payment vehicle. Almost all household in urban areas have service pipes connected to the municipal water and sewer mains. Thus, almost all households in Norway pay, usually quarterly, for disposal and treatment of sewage as part of their municipal charges bill. This bill also includes payment for the provision of drinking water, waste collection and chimney sweeping. Thus, an increase in municipal charges was found to be the most appropriate payment vehicle for this study. It is important to note that the payment vehicle in both scenarios (A and B) was identical; i.e. an increase in households´ annual bill for municipal services.

In scenario A, the payments would cover investment costs in flood prevention measures. In scenario B, payments would cover an additional insurance the municipalities would buy in order to compensate households affected by floods for any expenditure the households would have in excess of what their insurance covers. This could be deductibles, and reduction in compensation due to old age of affected objects. Thus, in scenario A, household payments would avoid the flood, while in scenario B, their payments would not, but their damage costs from floods would be fully covered.

A payment card (Navrud et al., 2008, Bateman, 2002) was used to elicit households´ WTP for CV scenarios A and B. The payment card consisted of a horizontal line with different amounts ranging from 0 to 12 000 NOK[2], but avoiding round numbers like 500 and 1000. The respondents were asked to move the cursor on the line from a starting point to the very left of 0 NOK to the highest amount their household would be willing to pay. They could also select the options; "uncertain/don't know" and "Other amount, please specify the amount". They had to move the cursor or select one of these two options, to be allowed to continue the survey. This procedure secures high item response rates in internet surveys. The respondents were then asked the following WTP-question:

"How much is the most, if anything, your household certainly is willing to pay in increased municipal charges pr. year to …?"

A payment card is especially suitable for internet surveys. Depending on their answer, the respondents were then routed to debriefing /follow-up questions; either *"What is the main reason you are willing to pay something for..?" or "What is the main reason you are not willing to pay anything for..?". These questions were important during* the pre-testing to check whether the CV scenarios and WTP questions worked well, but were also used in the main survey to identify possible invalid reasons for paying and to identify zero protests bid (i.e. reasons that they are not motivated by the welfare loss from insecurity from flooding we aim to estimate). As we had two CV scenarios, A and B, they had to go through this procedure twice. After having stated their WTP for A and then B, their two WTP amounts were displayed side by side in the same screen, and they were asked whether they would keep the amounts or revise them. The respondents were also told in an advance disclosure procedure that they would be asked to value two scenarios. These two procedures were put in place to make respondents aware of the difference between the two scenarios.

Results and discussion

The results showed that 863 out of 1060 respondents stated their WTP for *both* wtpA and wtpB. However, 5 % of them protested by answering zero WTP and stating *"I pay more than enough in municipal charges" as the main reason for not being willing to pay anything*. Thus, it seemed like 95% of the respondents accepted increased municipal charges as a realistic and fair payment vehicle.

We apply the Interval Midpoint WTP-model (Tian et al., 2011, Cameron and Huppert, 1989) to estimate respondents´ WTP from their response to the payment card. The method assumes that respondents´ "true" WTP lies at the midpoint between the selected amount and the next WTP amount (to the right) on the sliding scale. For respondents stating the lowest value ("0

[2] 1NOK = €0,11 (2015)

NOK") and the highest value ("12 000 NOK" or "more than 12 000 NOK, please state the amount") these exact amounts were used as their "true" WTP.

In the following, WTP for scenario A (preventive measures) and scenario B (insurance), are denoted wtpA and wtpB, respectively. WTP to avoid the insecurity for urban flooding; i.e. wtpA minus wtpB, is denoted wtpAB.

This section is structured as follows: First, we describe the exclusion criteria and categories of respondents excluded from the gross sample in order to define the *net* sample used for the econometric (regression) analysis. Second, we present descriptive statistics of the net sample for the explanatory variables used in the econometric analyses. Third, we present the results from the econometric analysis of wtpAB in terms of Probit and Ordinary Least Square (OLS) models. These models are also tests of criterion validity; i.e. whether WTP varies with determinants as expected from economic theory and results from previous CV surveys. The statistical software R ®, version 3.2.0 and R-studio®, version 0.98.1103 were used for the analysis. Fourth, we present mean WTP estimates for the value of avoiding insecurity from urban floods (mean wtpAB), for use in CBAs of preventive measures.

Exclusion criteria

We excluded respondents with missing or unreliable responses to the WTP-questions. According to Bateman (2002), these should include the following three categories:

i) "Don't know"- responses to the WTP-questions.

ii) "Protest zeros", i.e. respondents stating WTP=0, and selecting one alternative which reveal that they have not stated their "true" WTP. Thus, they have a positive WTP, but state zero WTP because they protest some part of the CV scenario. Response options regarded as protest zeros were: "The authorities should pay for/do more for preventive measures", "I already pay enough in municipal charges", and "I think alternative A (or B) seems unrealistic". These responses confirmed that they protested against the CV scenario, and that they very well could have a "true" positive (non-zero) WTP. Thus, counting these responses as zero WTP could underestimate mean WTP, and the respondents should therefore be excluded from the sample (Navrud et al., 2008). Respondents stated wtpA and wtpB separately and had to provide the main reason for zero WTP for each of them. Answers for "real" zero bids were i.e. "I cannot afford to pay", and "It is not worth anything to me". Among those that stated zero WTP, there were 51 (out of 165) and 118 (out of 276) zero protest bidders for scenarios A and B, respectively. In order to determine what characterize the zero protest bidders, probit models of protest zeros bids versus real zero bids were regressed against socioeconomic variables (*Age, Male, LogHouseInc, HighEducation*, *Worker* and *Basement*). The only significant explanatory variable (at the 10 % level) of the variables listed in table 3 was *Male* for scenario B. Thus, men provide more protest zeros than women when asked their WTP in terms of increased insurance.

iii) Unrealistically high WTP bids; i.e. respondents who refuse to take the survey seriously and/or provide unrealistically high bids. Only one respondent was identified in this category.

Table 2 shows the number of respondents for each of these three categories. Furthermore the table reports the number of inconsistent non-zero WTP bids, defined as wtpAB being negative, meaning wtpA < wtpB. This probably means that these respondents did not believe that the preventive measures in scenario A will be undertaken and/or effectively can avoid all future floods, or they valued B higher than A by mistake. As scenario A should make households better off , or at least as well off as B, respondents with wtpAB<0 was removed from further analysis. Thus, the net sample consisted of 643 respondents, out of which 311 and 332 had positive and real zero WTP, respectively, to avoid insecurity from urban flooding.

Table 2:

Table 3 provides summary statistics and descriptions of the explanatory (independent) variables of the net sample used in this analysis, including variable names. As seen from the first column in table 3, dummy variables were constructed from merging several reply options from the questionnaire. Four of the variables in the table characterize physical and mental "closeness" to urban floods. These were considered important and are presented and discussed in tables 4-6. These variables tell if the respondents are exposed to or annoyed by urban floods and if they have experienced an urban flood in their own house or knew any flooded houses in the region.

Table 3:

Econometric analysis

According to economic theory, WTP should increase with income. Most CV studies find a significant, positive effect of income on WTP, and usually the income elasticity of WTP is less than 1 (Kristrom and Riera, 1996, Bateman, 2002). This means that a 1 % increase in income leads to a less than 1 % increase in WTP. According to Carson and Flores (2000) there is, however, no straight forward relationship between the income elasticity of WTP and income elasticity of demand, where the latter is used to define whether we have a normal good or a luxury good (with income elasticities of demand below and above 1, respectively). To examine this, we estimated OLS models, which included *PersonalIncome* or *HouseholdIncome* (Never both at the same time as they are of course closely correlated) as well as socioeconomic variables (Age, Male, HighEducation, Worker and Basement) as predictors (see table 3 for definitions). The net sample consisted of two almost equally sized groups of respondents stating WTP=0 and WTP>0, respectively. Additionally, the majority of WTP>0 responses were small amounts. Thus, the WTP distribution was obviously skewed to the left.

As dependent variables, we used wtpA, wtpB and wtpAB, respectively, in separate models. These WTP-variables, as well as the income variables were log-transformed, which means the regression coefficient for income variable is the income elasticity of WTP[3]. However, for wtpAB, income was not significant (at the 10 % level), neither with income as the only variable nor when we added the socioeconomic variables of Age, Male, HighEducation, Worker and Basement. Running the same OLS models of wtpAB, but only for those exposed to urban flooding (i.e. *Exposed* =1; see table 1), we got the same result. In OLS models of wtpA and wtpB (with only positive values, as for wtpAB), we found a significant and positive income elasticity for wtpB when regressing on personal income only (0,49), and when adding socioeconomic variables (0,47). For the other models, the income elasticity of WTP was not significantly different from zero. This indicates that people think preventive measures (wtpA) are important to pay for, independent of their income. It seems easier for them to state their WTP in terms of insurance, and wtpB seems to be more dependent on their income. This is in agreement with the findings for pluvial floods by Grann (2011).

Tables 4-6 present 13 regression models of WTP to avoid insecurity of urban floods (wtpAB). Due to the skewed distribution of wtpAB, we were not running a joint model for the entire net sample, but rather two types of separate models: i) explaining *why* respondents were willing to pay something or not to avoid the insecurity (probit models); and ii) models only for those that were willing to pay something in order to find which factors determined *how much* they were willing to pay (OLS models). Thus, table 4 (models 1-5) shows probit models with the dependent variable being whether they had positive wtpAB or not (i.e. taking the value 1 when wtpAB>0 and zero if wtpAB=0. Table 5 (models 6-10) are OLS-models only for households that stated positive WTP (i.e. wtpAB>0). Finally, table 6 (models 11-13) is a more detailed version of table 5, where some significant variables are further separated into categorical value based on the response options.

All models include all independent variables from table 3, except *PersInc*. One general requirement for reliable models are uncorrelated parameters. Due to the high collinearity between all *PersInc* and *HouseInc* (R=0,74), one of them had to be excluded. *HouseInc* was preferred, as respondents were asked for household WTP (in terms of increased annual municipal charges), which is of course determined not only by personal income, but the overall household income. Observed collinearity between the three "flood variables" *Exposed*, *Annoyed* and *OwnExperience* (R varies between 0,37 and 0,56) could have biased the results in Model 1. Furthermore, there was weak correlation between these three variables and the variable *DistantFlood* (R varies between 0,22 and 0,24).

[3] The log transformation also contributed positively to making the skewed distribution of WTP (as in most CV studies) closer to the normal distribution (Pevalin and Robson, 2009)

As these four variables characterize some aspect of what we have previously referred to as "closeness to flooding", they seem to be important determinants for WTP. For models 2-5 and 6-10, we only included one of them at a time, to see which of them best explained the variation in WTP. Socio-economic variables showed very little correlation, and were thus included in all models.

Table 4:

Table 5:

In Model 1 *PayOther* is significant and positive (at the 1 % level), showing that people who answered "yes" to the statement "*I want to pay for others in the community to have their risk of flooding reduced*" have higher probability of stating positive WTP for avoiding insecurity than those that say "no" to this statement. Model 6 goes on to show that WTP for the latter group is lower than for the former; for those with positive WTP. This type of altruism does not represent double-counting when aggregating over all households, as people gain utility from knowing others get more secure (and know that these other people have to pay increased municipal charges to avoid insecurity).

Age is positive and significant (at the 10% level) in models 7 and 8, indicating that WTP to avoid insecurity from urban floods increase with age for those with wtpAB>0. This could be explained by the fact that older people fear the damages from flooding more as they dread both the impacts and work connected to the clean up. This is confirmed by models 1-5, where *Age* is significant and negative, showing that the probability of having wtpAB=0 is higher among young people. Models 2-5 imply that men are more likely than women to state wtpAB = 0. Comparing models 5 and 10, we see that while *OwnExperience is* highly significant with a positive sign in model 10, this variable is not significant in model 5. This indicate that having experienced floods does not influence the decision on whether you are willing to pay something or not, but if you have positive WTP, it is higher if you have had this experience.

Models 6-10 show that all four "closeness variables" are significant (at the 5% level) and positive, confirming our theoretical expectation that people feeling "close to flooding" have higher WTP to avoid insecurity from flooding than those that don´t (given that they have wtpAB>0) . Each of these "closeness variables", except *OwnExperience*, have several reply options. In order to see whether each reply option is significant, we re-ran Models 7-9, but now with each category as a dummy (with the exception of the "hidden options" of *"Not exposed at all", "Not annoyed at all"* and "*No – I don't know any others within my region affected by floods* for the *Exposed*, *Annoyed* , and *DistantFlood* variables; respectively).

Table 6:

The results presented in table 6 show that the most exposed, annoyed and knowledge of flood damages within 100 m of their home, have a significantly higher WTP than those that are not exposed, not annoyed or do not know about flood damages in their region, respectively.

Even if *Age* is significant at 10% level in models 11 and 12, none of the demographic variables seemed to affect WTP as much as *Exposed, Annoyed* and *DistantFlood* do.

According to Carson and Flores (2000), it is reasonable to assume that respondents who are "closer" to flooding, both literally and figuratively, should also have a higher probability of paying for an increment in the public good "security against flooding", than people with little experiences in this regards. Results in tables 4, 5 and 6 confirm this hypothesis.

Calculating mean WTP

Based on the net sample of 643 respondents (see table 2), we can calculate *mean* WTP for avoiding insecurity from urban flooding (i.e. for all respondents with wtpAB ≥ 0). Mean WTP is the correct welfare measure in Cost-Benefit Analysis of the preventive measures, and would be aggregated over the number of affected households for each project in order to estimate the aggregate social benefits from avoiding insecurity. However, as we have seen above, WTP varies with "closeness to flooding". This means that if we used our mean WTP estimate in CBAs, we would implicitly assume that the distribution across different levels of closeness to flooding would be the same at the site of the specific flood prevention project (of which we were conducted a CBA) as the distribution in our sample. This is probably not the case as our sample was not representative of the overall population. Here, 20% of the respondents stated that they were prone to flooding, while for the overall population the number is probably less than 5 %. Thus, conducting a CBA of preventive measures nationwide, using the mean WTP estimate from our survey, multiplied by the total number of Norwegian households, would produce a biased aggregate benefit estimate. To correct for this, we will present estimates of mean WTP for each category of the "closeness to flooding" variables, and multiply these estimates with the corresponding number of affected households in each of these categories.

The same would apply to the demographic variables, if the sample is not representative of the affected households at the project site where we will perform a CBA, whether this is a local or a national flood prevention project/plan. Our sample was not representative of the Norwegian population with regards to income and education, as both were higher in our sample than in the Norwegian population (SSB, 2016a, SSB, 2016b). However, as opposed to the "Closeness of flooding" variables, none of these variables had a significant impact on WTP. Thus, there was no reason to make adjustments for these demographic variables.

Table 7 shows the WTP for each category of the "Closeness to flooding" variables: Exposed, DistantFlood and OwnExperience. The fourth closeness variable, "Annoyed" , (even though also significantly affecting WTP) was found to be difficult to use in CBAs of preventive measures as it would be hard to find the distribution of the affected population on the different categories of this variable. However, for the other three variables this should be possible, and enable the calculation of aggregate benefits of a national flood prevention plan.

Table 7:

As expected, households´ WTP increased with higher levels of each of the three "closeness to flooding" variables. If we compare the highest level/category of "Closeness to flooding" across the three variables (*Exposed3*, *DistantFlood3* and *OwnExperience1*) we see that the lowest WTP estimate belongs to respondents with personal experience with flooding (*OwnExperience1*). This indicates more insecurity among those who believe they can be affected (reflected in the *Exposed* and *DistantFlood* variables), than those who actually have been affected (*OwnExperience*). This could be explained by people having experienced flood damage thinking it was not so bad as they had expected, and/or that these people later on have put in place preventive measures (e.g. moving all valuable in the basement to a higher floor), which have made them worry less about the possible damages from future urban floods.

For those not exposed or affected (i.e. the lowest category of "closeness to flooding" in all these three variables), mean WTP /Household/year is quite stable around 400 NOK[4].

For practical purposes, we believe that the WTP estimates from the variable based on Distance to other areas with floods (*DistantFlood*) is most appropriate to use in CBAs of smaller projects. If the authorities should initiate a preventive flood project, it is usually because more than one household is exposed. This is because it is easy to map different zones based on distances from former flood affected areas. Moreover, the small number of observations (respondents) for the most affected categories makes the mean WTP estimate for these categories more uncertain than for the others. As a conservative, lower estimate, we suggest insecurity cost within the 1 km zone from the previously affected areas to be 800-900 NOK per household per year. Outside this zone, we suggest using a WTP of 400 NOK per household per year.

As there, to our knowledge, are no previous studies specifically valuing insecurity of pluvial floods, we compare our results to WTP estimates from two previous studies of impacts from fluvial (river) floods. DEFRA/EAF (2004) conducted a survey in the UK to calculate the health benefits from reduced flood risk. They recommended a value of £200 (2004) per household per year for affected households. Using a Purchase Power Parity (PPP)-corrected exchange rate between UK £ and NOK in 2004, and adjusting with the Norwegian Consumer Price Index (CPI); from 2004 until 2015 (the year of our study) this corresponds to about 3000 NOK (2015). Grann (2011) conducted a CV study near the urban center of Drammen, Norway in 2011, and found a mean WTP/household/year for avoiding the insecurity from river flooding to be about 99 NOK (2015) (adjusted with the CPI from 2011 to 2015). Note that this is the mean WTP over *all* categories of exposure to floods. Even if Drammen is considered to be exposed to floods, there had been no disastrous river floods just before the survey was conducted, which there had been prior to the UK CV survey. This might be one explanation for the difference in WTP between the two studies.

[4] 1NOK = €0,11 (2015)

Conclusion

If the benefit of reduced insecurity for urban flooding is valued, social benefits of avoiding these floods will increase. This can justify implementing a higher number of preventive measures, and change the ranking of projects involving these measures (Navrud and Magnussen, 2013, Navrud et al., 2012). The outcome of this Contingent Valuation (CV) study should thus be of interest to a wide range of stakeholders; including residents exposed to flooding, insurance companies, as well as urban planners and developers dealing with prioritization of flood prevention projects.

This study shows that it is possible to measure the willingness-to-pay (WTP) to avoid insecurity for urban flooding in a CV survey. There are some limitations of the study. As 39% of the respondents had to be excluded from the gross sample due to inconsistencies in their WTP answers, protest zero answers, or that they answered, "Don´t know" to the WTP questions; the sample size from 1060 to 643 observations. However, we have no indication this reduce the representativeness of the sample. Furthermore, for households most exposed to urban floods there are relatively few observations, making WTP estimates for this group more uncertain than for the lower levels of flood exposure.

While demographic variables have no significant impact on WTP for avoiding insecurity (with the possible exceptions of age and gender), measures of physical and psychological closeness to flooding seem to be significant. The survey indicates that people who do not regard flooding as a big concern, have a mean WTP /household/year of about 400 NOK while those who are concerned are on average willing to pay 2-3 times this amount annually to avoid the insecurity.

The valuation method applied here, and the results of this study, can serve at least three purposes:

1. Social benefits of avoiding insecurity can be included in CBAs of measures/projects/plans to prevent urban flooding, and similar benefits should be added for other types of floods (e.g river floods). DEFRA/EAF (2004) state that more "tangible" losses from flooding (property damages etc) are the largest components of flood damage costs, but that inclusion of health impact can change the ranking of prevention projects. This is due to the fact that unlike the "one-time costs" of physcial property damage associated with individual flood events, the insecurity from the risk of flooding is a "continuous cost" for the affected households. Although, households´ annual "cost" of insecurity is limited, and will fluctate with changing weather and over seasons, these costs could easily add up to a significant amount when aggregated over time for all affected households.

2. CV studies like ours can shed light on a hidden everyday psycological challenge for some people, which others do not care much about. Raising awareness of the insecurity costs may lead to simple solutions to some flooding problems. For example, neighbours living in higher elevation can be informed that they should carefully consider where to drain their rainwater to reduce the insecurity of flooding to people downhill. Simple information and awareness raising measures like this can be implemented in affected small urban areas by local authorities without initiating expensive technical projects.

3. This way of measuring the social benefits of avoiding insecurity of flooding caused by rainwater can be relevant for river flooding and other natural hazards like landslides. However, our study does not look at events with disastrous and fatal consequences. Thus, we believe that the results from our study apply primarily to an urban flood context, but could also be used illustrate the magnitude of insecurity costs from other natural hazards causing the same type and level of physical damage.

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References

ALBERINI, A. & KAHN, R. J. 2006. *Handbook on Contingent Valuation,* Cheltenham, UK, 'Edward Elgar Publishing, Inc.'.

BATEMAN, I. 2002. *Economic valuation with stated preference techniques: a manual,* Cheltenham, Elgar.

BOTZEN, W. J. W., AERTS, J. C. J. H. & VAN DEN BERGH, J. C. J. M. 2009. Willingness of homeowners to mitigate climate risk through insurance. *Ecological Economics,* 68**,** 2265-2277.

BROUWER, R., AKTER, S., BRANDER, L. & HAQUE, E. 2007. Socioeconomic vulnerability and adaptation to environmental risk: A case study of climate change and flooding in Bangladesh. *Risk Analysis,* 27**,** 313-326.

CAMERON, T. A. & HUPPERT, D. D. 1989. OLS versus ML estimation of non-market resource values with payment card interval data. *Journal of Environmental Economics and Management,* 17**,** 230-246.

CARSON, R. T. & FLORES, N. A. 2000. Contingent Valuation: Controversies and Evidence.

CETTNER, A., ASHLEY, R. M., HEDSTRÖM, A. & VIKLANDER, M. 2012. Sustanable development and urban stormwater practice. *Urban Water Journal*.

CHATTERTON, J., VIAVATTENE, C., MORRIS, J., PENNING-ROWSELL, E. & S., T. 2010. The cost of the summer 2007 floods in England. *In:* DEFRA, D. F. E., FOOD AND RURAL AFFAIRS (ed.).

DEFRA/EAF 2004. *The Appraisal of Human-related Intangible Impacts of Flooding*, Defra.

ELVIK, R. 2006. *Economic valuation of non-market goods in transport: the need for new valuation studies and discussion of methods (In Norwegian: Økonomisk verdsetting av ikke-markedsgoder i transport: behovet for nye verdsettingsstudier og drøfting av metoder),* Oslo, Norwegian Center for Transport Research (In Norwegian: Transportøkonomisk institutt).

GRANN, S. L. 2011. *Insecurity of flooding: a contingent valuation study (In Norwegian: Utrygghet for flom: en betinget verdsettingsstudie), Master thesis NMBU.*

JHA, A. K., BLOCH, R. & LAMOND, J. 2012. *Cities and flooding: a guide to integrated urban flood risk management for the 21st century*, World Bank Publications.

KRISTROM, B. & RIERA, P. 1996. Is the income elasticity of environmental improvements less than one? *Environmental and Resource Economics,* 7**,** 45-55.

LINDHJEM, H. & NAVRUD, S. 2011. Using Internet in Stated Preference Surveys: A Review and Comparison of Survey Modes. *International Review of Environmental and Resource Economics,* 5**,** 309-351.

LINDHOLM, O., ENDRESEN, S., THOROLFSSON, S., SÆGROV, S., JAKOBSEN, G. & L., A. 2008. *Guidelines for climate adapted stormwater management (In Norwegian: Veiledning i klimatilpasset overvannshåndtering),* Hamar, Norway, Norsk Vann BA.

MCMAHON, P., MORAN, D., SUTHERLAND, P. & SIMMONDS, C. 2000. Contingent Valuation of First-Time Sewerage Provision in South-East England. *Water and Environment Journal* 14**,** 277–283.

MESSNER, F., PENNING-ROWSELL, E., GREEN, C., MEYER, V., TUNSTALL, S. & VAN DER VEEN, A. 2007. Evaluating flood damages: Guidance and recommendations on principles and methods. http://www.floodsite.net/html/partner_area/project_docs/T09_06_01_Flood_damage_guidelines_D9_1_v2_2_p44.pdf.

NAVRUD, S., HUU TUAN, T. & DUC TINH, B. 2012. Estimating the welfare loss to households from natural disasters in developing countries: a contingent valuation study of flooding in Vietnam. *2012,* 5.

NAVRUD, S. & MAGNUSSEN, K. 2013. *Valuing the Impacts of Natural Disasters and the Economic Benefits of Preventing them. Chapter 3 (p. 57-79) in Guha-Sapir, D. & I. Santos (eds.) The Economic Impacts of Natural Disasters.* .

NAVRUD, S., READY, R. C., MAGNUSSEN, K. & BERGLAND, O. 2008. Valuing the social benefits of avoiding landscape degradation from overhead power transmission lines: Do underground cables pass the benefit-cost test? *Landscape Research,* 33**,** 281-296.

NGAF 2014. Cost-Benefit Analysis (In Norwegian: Samfunnsøkonomisk Analyse). *In:* NORWEGIAN GOVERNMENT AGENCY FOR FINANCIAL MANAGEMENT (NGAF) (IN NORWEGIAN: DIREKTORATET FOR ØKONOMISTYRING) , O., NORWAY (ed.).

NPRA 2014. Impact Analysis (In Norwegian: Konsekvensanalyse). *In:* NORWEGIAN PUBLIC ROAD AUTHORITY (NPRA), O., NORWAY (ed.) *Handbook V712.*

PEVALIN, D. & ROBSON, K. 2009. *Stata Survival Manual (1),* Berkshire, GB, Open University Press.

RASMUSSEN, J. Adaption to climate change in Copenhagen - cloudburst (In Danish: Klimatilpasning i København - Skybrud). *In:* NTVA, ed. Teknisk naturvitenskapelig kunnskap i samfunnssikkerhetsarbeid, 2014 Trondheim.

SEMADENI-DAVIES, A., HERNEBRING, C., SVENSSON, G. & GUSTAFSSON, L.-G. 2008. The impacts of climate change and urbanisation on drainage in Helsingborg, Sweden: Suburban stormwater. *Journal of Hydrology,* 350**,** 114-125.

SSB. 2016a. *Population´s level of education, 1 October 2015* [Online]. Available: https://ssb.no/en/utdanning/statistikker/utniv [Accessed].

SSB. 2016b. *Tax statistics for personal tax payers, 2015, preliminary figures* [Online]. Available: https://www.ssb.no/en/inntekt-og-forbruk/statistikker/selvangivelse [Accessed].

TAIT, S. J., ASHLEY, R. M., CASHMAN, A., BLANKSBY, J. & SAUL, A. J. 2008. Sewer system operation into the 21st century, study of selected responses from a UK perspective. *Urban Water Journal,* 5**,** 77-86.

TIAN, X., YU, X. & HOLST, R. 2011. Applying the payment card approach to estimate the WTP for green food in China. *In:* (IAMO), L. I. O. A. D. I. T. E. (ed.) *"Will the „BRICs Decade" continue? - Prospects for trade and growth".* Halle (Saale), Germany.

WILLEMS, P. 2012. *Impacts of climate change on rainfall extremes and urban drainage systems,* London, IWA publishing.

Table 1: Precipitation damage to residential housing. Three levels defined and shown to the respondents in the internet survey. Level 2 is the subject of the Contingent Valuation scenarios, which in this paper is termed "urban floods" (Photos: level 1: Geir Torgersen, level 2: Tore Øyvind Moen, Varden and level 3 Helge Mikalsen, VG)

Level	**Character-istics**	**Possible causes**	**Possible damage**	
1.	Moisture/ small damage to property	Poor drainage around house, leaky roofs etc.	Small	
2.	Small floods / inundation	Pluvial flood due to insufficient sewer and drainage capacity	Substantial	
3.	Extensive floods	Fluvial flooding due to overflowed river	Disastrous	

Table 2: Number of respondents (N) in gross sample, excluded for different reasons and net sample

Category	**N**
Net sample	
wtpAB >0	311
wtpAB =0	332
SUM NET SAMPLE	**643**
Excluded	
Don't knows (DK) for wtpA or/and wtpB	197
Protest bid for wtpA or/and wtpB	131
Unrealistically HIGH value of bidsfor wtpA or/and wtpB, WTP > 15 000 NOK	1
wtpAB <0	88
SUM GROSS SAMPLE	**1060**

Table 3: Summary statistics for explanatory variables for the net sample[5]

Variables	Variable name	N	Mean	SD
Age (in years)	Age	643	46,82	15,40
IncomePerpers 2015 (NOK)	PersInc	561	558 289	326 245
IncomeHousehold 2015 (NOK)	HouseInc	557	814 542	440 185
Male (1= male / 0 = female)	Male	643	0,49	0,50
Higher education (1= College, University)/ 0= other)	HighEducation	639	0,72	0,45
Worker (1= worker/ 0= retired / social security recipient /student/unemployed/homeworker)	Worker	643	0,68	0,47
Basement in own resident (1= yes / 0 = no)	Basement	643	0,71	0,45
Exposed to flooding? (1 = highly, very, pretty much / 0 = little, not at all)	Exposed	627	0,20	0,40
Annoyed by insecurity to flooding? (1 = highly, very, pretty much / 0 = little, not at all)	Annoyed	643	0,07	0,26
I know others in my region affected by flooding (yes within 1 km = 1/ others = 0)	DistantFlood	643	0,33	0,47
Experience of flooding at home at own house (1= yes/0=no)	OwnExperience	643	0,10	0,30
I want to pay for others to get a reduction in their risk of urban flooding (1=I agree, somewhat agree, neutral /0=I disagree, somewhat disagree)	PayOther	630	0,69	0,46

[5] 1NOK = €0,11 (2015)

Table 4: Regression models 1-5 (Probit) with the probability of having positive WTP for avoiding the insecurity from urban floods as the dependent variable (wtpAB>0 defined 1 and wtpAB=0 is defined as 0).

Probit **1= wtpAB>0 / 0= wtpAB=0**	Model 1 (probit)		Model 2 (probit)		Model 3 (probit)		Model 4 (probit)		Model 5 (probit)	
N=	536		544		556		556		556	
Variables	z value	Pr(>|z|)	z value	Pr(>|z|)	z value	Pr(>|z|)	z value	Pr(>|z|)	z value	Pr(>|z|)
Age	-2,64	**0,01*****	-2,26	**0,02****	-2,37	**0,02****	-2,59	**0,01*****	-2,47	**0,01****
Male	-1,63	0,10	-1,85	**0,06 ***	-1,72	**0,09 ***	-1,72	**0,08 ***	-1,79	**0,07***
LogHouseInc	-0,88	0,38	-0,79	0,43	-0,80	0,42	-0,90	0,37	-0,80	0,42
HighEducation	1,18	0,24	1,53	0,13	1,35	0,18	1,38	0,17	1,36	0,18
Worker	-1,14	0,25	-1,23	0,22	-1,27	0,20	-1,29	0,20	-1,26	0,21
Basement	0,82	0,41	0,47	0,64	0,49	0,62	0,60	0,55	0,77	0,44
Exposed	0,87	0,38	2,66	**0,01*****						
Annoyed	1,95	0,05			2,84	**0,00*****				
DistantFlood	1,38	0,17					2,17	**0,03****		
OwnExperience	-0,74	0,46							1,15	0,25
PayOther	4,44	**0,00*****								
(Intercept)	1,00	0,32	1,15	0,25	1,20	0,23	1,30	0,19	1,21	0,23

Note: ***, ** and * are significant at 1%, 5% and 10 % level

Table 5: Regression models 6-10(Ordinary Least Square) with WTP to avoid insecurity from urban floods as the dependent variable (only for those with wtpAB>0).

OLS wtpAB>0	Model 6 (OLS)		Model 7 (OLS)		Model 8 (OLS)		Model 9 (OLS)		Model 10 (OLS)	
N	270		273		279		279		279	
Adjusted R^2 =	0,09		0,04		0,05		0,03		0,05	
Variables	t value	Pr(>|t|)	t value	Pr(>|t|)	t value	Pr(>|t|)	t value	Pr(>|t|)	t value	Pr(>|t|)
Age	1,59	0,11	1,80	**0,07***	1,71	**0,09***	1,52	0,13	1,64	0,10
Male	-0,57	0,57	-0,65	0,51	-0,57	0,57	-0,57	0,57	-0,76	0,45
LogHouseInc	0,05	0,96	0,19	0,85	0,36	0,72	0,19	0,85	0,45	0,66
HighEducation	0,40	0,69	0,71	0,48	0,56	0,58	0,58	0,56	0,28	0,78
Worker	-0,95	0,34	-1,07	0,28	-1,17	0,24	-1,09	0,28	-1,09	0,28
Basement	1,32	0,19	1,05	0,30	1,27	0,21	1,51	0,13	1,46	0,14
Exposed	0,69	0,49	2,53	**0,01 ** **						
Annoyed	1,02	0,31			2,91	**0,00 *** **				
DistantFlood	1,39	0,16					2,28	**0,02 ** **		
OwnExperience	1,44	0,15							3,36	**0,00 *** **
PayOther	3,18	**0,00 *** **								
(Intercept)	3,93	0,00 ***	3,98	0,00 ***	3,93	0,00 ***	4,05	0,00 ***	3,87	0,00 ***

Note: ***, ** and * are significant at 1%, 5% and 10 % level

Table 6: Regression models 11-13 (Ordinary Least Square) with WTP to avoid insecurity from urban floods (only for those with wtpAB>0) as the dependent variable. The independent variables Exposed and DistantFlooding are here categorical variables.

	Model 11 (OLS)		Model 12 (OLS)		Model 13 (OLS)	
N	273		279		279	
Adjusted R^2 =	0,05		0,06		0,04	
Variables	t value	Pr(>|t|)	t value	Pr(>|t|)	t value	Pr(>|t|)
Age	1,75	**0,08 ***	1,71	**0,09 ***	1,43	0,15
Male	-0,68	0,50	-0,74	0,46	-0,68	0,50
LogHouseInc	0,08	0,93	0,16	0,88	0,32	0,75
HighEducation	0,84	0,40	0,34	0,73	0,49	0,62
Worker	-0,99	0,32	-1,01	0,32	-1,25	0,21
Basement	1,16	0,25	1,44	0,15	1,28	0,20
Exposed1 (little)	-1,81	**0,07 ***				
Exposed2 (quite)	0,48	0,63				
Exposed3 (much and very)	2,22	**0,03 ****				
Annoyed1 (little)			-1,85	**0,07 ***		
Annoyed2 (quite)			0,88	0,38		
Annoyed3 (much and very)			3,04	**0,00 *****		
DistantFlood1 (within own region, >1 km away)					0,83	0,41
DistantFlood2 (between 100m and 1 km away)					1,52	0,13
DistantFlood3 (< 100 m away)					2,85	**0,00 *****
(Intercept)	4,21	0,00 ***	4,23	0,00 ***	3,97	0,00 ***

Note: ***, ** and * are significant at 1%, 5% and 10 % level

Table 7: Willingness-to-pay (WTP) per household per year (in terms of increased municipal charges) to avoid insecurity from urban floods, for different categories of three variables/measures of "closeness to flooding" ; Self- assessed exposure to urban floods at own home (Exposed), distance to others that had experienced floods (DistantFlood), and experience with flooding at own home (OwnExperience).

WTP-values in Norwegian Kroner (NOK) **1 NOK = 0,11€ (2015)** Variables	Median wtp	Mean wtp	SE mean	N
Exposed 0 (no)	0	399	63	227
Exposed1 (little)	150	416	56	273
Exposed2 (quite)	250	665	115	99
Exposed3 (much and very)	425	1200	465	28
Exposed (NA)	0	350	161	16
DistantFlood0 (Do not know any floods within region)	0	367	32	434
DistantFlood1 (within own region, >1 km away)	150	584	126	115
DistantFlood2 (between 100m and 1 km away)	300	693	192	63
DistantFlood3 (< 100 m away)	400	1255	425	31
OwnExperience0 (No)	0	432	39	581
OwnExperience1 (Yes)	275	938	243	62

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